Climate Change and the Macroeconomics of Bank Capital Regulation*

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Abstract

This paper proposes a quantitative multi-sector DSGE model with bank failure and firm default to study the interactions between bank regulation and climate policy. Households value the liquidity of deposits, which are protected by deposit insurance. Banks collect deposits and issue equity to extend defaultable loans to clean and fossil energy firms. Bank capital regulation affects liquidity provision to households, bank risk-taking, and loan supply across sectors. Using a calibrated version of the model, we obtain four results: first, fossil penalizing capital requirements can be discarded as climate policy instrument, since their effect on sector-specific investment is quantitatively negligible in general equilibrium. Second, *Ramsey-optimal* capital requirements in response to a tax-induced clean transition decline to counteract negative loan demand effects. Third, differentiated capital requirements are only necessary if banks are not perfectly diversified across sectors. Fourth, nominal rigidities induce a temporary tightening of capital requirements if the transition is inflationary and, thus, spurs a boom on the loan market.

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1 Introduction

Limiting the adverse effects of anthropogenic climate change to a manageable level is one of the largest challenges for economic policy in the next decades. Addressing this issue is only feasible with drastic changes to the production sector, including a shift away from fossil to clean energy sources. How such a sectoral reallocation and the financial flows it generates affects the conduct of optimal bank capital regulation is not well understood yet. For example, it is largely unclear whether differential capital requirements for clean and fossil sector loans can induce a quantitatively relevant re-allocation of funds towards the clean sector, in particular when they are benchmarked against carbon taxes. Furthermore, it remains an open question how bank capital regulation should *optimally respond* to a sectoral reallocation induced by carbon taxes.

This paper answers these questions through the lenses of a unified macroeconomic framework. To do so, we extend a multi-sector DSGE model by the possibility of bank failure and default risk in the real economy. Non-financial firms can finance their investment with equity and defaultable loans. Banks finance these loans by issuing equity or by extending deposits to households, who value deposits for their liquidity services. Depositors are protected from bank failure through deposit insurance that repays deposits using taxpayer funds in the case of bank failure. Deposit insurance and households' valuation of liquidity services together imply that deposit rates are always substantially lower than the risk-free rate. Bank owners are protected by limited liability. The deposit insurance put that banks exert on the government implies that banks' risk-taking decision, which is directly linked to their leverage ratio in this model, is inefficiently high. Tighter bank regulation decreases the bank failure probability and simultaneously reduces the provision of liquid deposits. The optimal bank capital requirement balances these effects.[1]

We link this representation of optimal capital requirements to a multi-sector

[1]A very similar trade-off arises when deposit insurance is interpreted as implicit bailout guarantees. This approach is common when studying bank capital requirements from a macroeconomic perspective, see for example Mendicino et al. (2020) and the references therein. Rationalizing bank capital requirements by a deposit insurance put or implicit bailout guarantees goes back at least to Kareken and Wallace (1978). VanHoose (2007) provides a comprehensive summary of early theories of bank capital regulation. Pennacchi (2006) demonstrates that deposit insurance is critical to bank liquidity provision but that it also creates moral hazard. Mishin (2023) provides an analysis in a DSGE model that shares features with our approach. Likewise, interpreting bank deposits as safe assets goes back at least to Gorton and Pennacchi (1990), while money in the utility specifications have been used extensively since the contribution by Poterba and Rotemberg (1986). Making households value the liquidity service of bank deposits has become a commonly used feature in the macro banking literature, see also the discussion in Begenau (2020).

production economy that features salient properties of the energy sector and carbon taxation. Specifically, final good producers combine intermediate inputs from three different sectors that consist of a representative clean energy, fossil energy, and non-energy firm, respectively. Fossil firms generate emissions in the production process, which are taxed by the government. We allow for costly emission abatement: fossil firms find it optimal to increase their abatement effort in response to a carbon tax hike (Heutel 2012), which has a direct impact on emissions and also reduces the return on fossil capital. In equilibrium, this return difference implies that the fossil capital share declines, reducing emissions even further.

Banks are linked to the production side through the market for corporate loans. On this market, bank capital regulation affects loan supply, since it determines the amount of costly equity banks need to raise per unit of loans. The demand for loans is shaped by two credit frictions on the production side, which give rise to an endogenous capital structure choice at the firm level. On the one hand, firms have an incentive to use debt financing. Banks fund themselves below the risk-free rate and pass on their relatively cheap financing conditions to the loan market: taking up a loan is less expensive than raising equity from households. On the other hand, taking up loans exposes firms to default risk. We assume that their production technology is subject to uninsurable idiosyncratic productivity shocks. Following Gomes, Jermann, and Schmid (2016), firms default on their loan obligations whenever their current revenues fall short of the due loan repayment. Firm default entails a restructuring cost for banks which is fully reflected in loan rates. The optimal loan take-up is determined by restructuring cost and the funding advantage of loans, which in turn depends on bank capital regulation.

We calibrate the model to match salient empirical features of financial markets and the effects of carbon taxes on the macroeconomy and across different production sectors. Using our calibration as a laboratory for different policy experiments, we first assess the suitability of bank capital regulation as a climate policy instrument. The insufficiently low levels of carbon taxes currently in place (World Bank 2019) have sparked interest in financial market instruments that can contribute to the transition to net zero. Among the most popular proposals are differentiated bank capital requirements for loans extended to clean and fossil energy firms.[2]

Qualitatively, fossil penalizing capital requirements reduce the return on fossil capital by making refinancing conditions in the fossil energy sector less attractive. Notably, without further strings attached, they do not affect the share of abated emissions. It is a quantitative question whether the sectoral reallocation induced by such a policy is macroeconomically relevant. We use our calibration to evaluate the effects of a fossil penalizing factor of 150%.[3] The macroeconomic effects of such

[2] A report by the Financial Stability Board (2022) discusses how climate change and climate policy can affect bank regulation. See also Oehmke (2022).

[3] Starting from a baseline equity requirement of 8%, this would correspond fossil capital

a policy are very small, since the equilibrium response of loan supply to elevated capital requirements is fairly small (see also the discussion in Kashyap, Stein, and Hanson 2010). We therefore allow for sustainability-linked capital requirements, which explicitly condition them on the abatement effort undertaken by fossil energy firms. Even in this case, the climate impact of this policy is smaller than even a very modest carbon tax. The induced emission reduction falls short by a factor of almost 100 relative to full abatement. We also show that fossil penalizing capital requirements generate unintended side effects on the supply of deposits, since aggregate loan demand contracts.[4] This essentially rules out differentiated capital requirements as climate policy instrument.

We then turn to optimal bank capital regulation along a net-zero transition induced by carbon taxes, which we *exogenously* impose on the model economy. To do so, we subject the economy to a linear tax path that increases from zero to 10 dollars per tonne of carbon. The increase is initially unanticipated, but all uncertainty resolves immediately upon announcement. Solving for the transition path to the new steady state non-linearly and under perfect foresight, we first study the sectoral and aggregate effects of the tax path. In a second step, we non-linearly solve for Ramsey-optimal bank capital regulation along the transition path.

The macroeconomic effects of the transition can be divided into *impact* effects, *short run* effects, and *long run* effects. On *impact*, fossil firms default more often than clean firms, which translates into a short-lived uptake in the bank failure rate. These instantaneous effects of an unanticipated transition are well-studied in the literature. The clean and fossil sector respond heterogeneously in the *short run*: clean firms have an incentive to increase their risk-taking going forward, resembling a clean credit expansion. At the same time, fossil firms face deleveraging incentives.[5] Notably, the sectoral shift in risk-taking and investment is not inefficient as far as bank regulation is concerned: firm risk-taking is fully reflected in loan prices and there is no market failure associated with corporate default in this model.[6] Without additional frictions, there is no scope for differentiated bank

requirement of 12%.

[4]In general equilibrium, clean energy and non-energy firms compensate the direct negative effect that fossil penalizing capital requirements have on investment and loan demand in the fossil sector. However, as long as intermediate goods from different sectors are not perfect substitutes, carbon taxes will have a contractionary effect on GDP and loan demand in the short run.

[5]We demonstrate that the short-run effects of the clean transition are very similar to the macroeconomic effects of carbon policy surprises.

[6]A recent strand of literature has focused on the macroeconomic effects of socially inefficient asset stranding. For example, Carattini, Melkadze, and Heutel (2023) argue that asset stranding can affect macroeconomic outcomes by tightening intermediaries lending capacity and, thereby, induces a credit crunch in all sectors. Using a model based on bank level data, Alessi et al. (2022) show that a small capital buffer suffices to protect the banking system from such a fire-

capital regulation along the clean transition.

Optimal bank capital regulation is, thus, affected by the clean transition in so far as sectoral effects translate into aggregate effects.[7] Clean, fossil, and non-energy goods are imperfect substitutes, such that aggregate credit demand contracts and banks reduce their balance sheets. This has two welfare relevant effects. First, banks provide less liquidity to households, such that the deposit spread widens. Second, this makes deposit financing cheaper for banks, such that they increase loan supply ceteris paribus. The change in refinancing conditions (partially) mitigates the negative loan demand effect, but this comes at the cost of higher leverage ratios and default rates in the corporate sector. Therefore, default risk increases symmetrically in the clean and fossil sector. To counteract these effects, optimal bank regulation declines to a lower *long run* level in a monotonic way.

We provide two model extensions that break the symmetry and monotonicity of the optimal path of bank capital regulation along the transition. First, we introduce nominal rigidities. In our model, the clean transition is inflationary in the short run, which is consistent with empirical evidence (Ciccarelli and Marotta 2021). If debt is denominated in nominal terms, this induces firms to increase their loan issuance. By catering to this loan demand, banks also increase deposits, which then implies that the bank regulator's trade-off is *temporarily* tilted in favor of reducing the bank failure rate. In the short-run, bank capital requirements tighten, before converging to the more lenient long run level.

In a second extension, we eliminate nominal rigidities but relax the assumption of perfect diversification of loan portfolios across sectors. While the aggregate effects of the transition are broadly consistent with the diversified case, optimal bank regulation trades off sector-specific deposit supply and bank failure rates. Specifically, the deposit supply of fossil (clean) banks is negatively (positively) affected in the short run, such that capital requirements are *temporarily* tightened for clean banks and relaxed for fossil banks. In the long run, both capital requirements converge to a lower level.[8]

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sale mechanism. In contrast, our analysis focuses on optimal bank regulation in response to an entirely different market failure, namely bank risk-taking vis-a-vis depositors that the regulator trades off against the supply of liquid bank deposits.

[7]Studying the aggregate effects of sector-specific shocks goes back to at least Horvath (2000). To the best of our knowledge, there is no analysis of optimal bank capital regulation in multi-sector DSGE models. The optimal policy results presented in this paper, therefore, are not restricted to the effects of climate policy along the clean transition, but also apply to sectoral re-allocations on a more general level.

[8]There are alternative market failures that might require regulators to differentiate their treatment of green and brown firms, such as the asset overhang studied in Degryse, Roukny, and Tielens (2022).

Related Literature. Our paper is related to two fast growing strands of literature. First, we contribute to the growing literature on interactions between financial frictions, climate change, and climate policy. There are several theoretical results on the relevance of financial frictions for the conduct of environmental or climate policy. Heider and Inderst (2022) and Döttling and Rola-Janicka (2022) show that financial frictions can impair the conduct of climate policy: if stringent carbon taxes induce inefficient liquidation of investment projects due to financial constraints, the optimal Pigouvian emission tax is lower than in the absence of financial frictions. In Fuest and Meier (2023), sustainable finance policies serve as a commitment device for carbon tax policies. Oehmke and Opp (2022) show that green capital requirements are an ill-suited instrument to initiate a transition to net zero: preferential green capital requirements might even increase lending to brown firms if the marginal project a bank can finance is a operated by a brown firm. On a conceptual level, the inferiority of differentiated capital requirements as climate policy instrument relative to carbon taxes also relates to Davila and Walther (2022) who develop a general framework of second-best regulatory policies.

We also contribute to the literature of financial policies in quantitative E-DSGE models. A series of recent papers has however studied green-tilted central bank policies in this class of models, such as green QE (Ferrari and Nispi Landi 2023 or Abiry et al. 2021) and green collateral policy (Giovanardi et al. 2023). These papers deliver a quantitatively similar result on the limited effectiveness of green-tilted central bank policies that are similar to our results on the limited efficacy of green-tilted capital requirements as climate policy instrument.

Annicchiarico, Carli, and Diluiso (2023) propose a model with climate policy and external financing constraints at the firm level, which can jointly amplify business-cycle fluctuations, such that macroprudential policy operates as stabilization instrument. In a similar setup, Diluiso et al. (2021) discuss how sector-specific capital requirements can mitigate negative shocks originating in the financial sector. Related to our results, sector-specific capital requirements only marginally improve on symmetrically adjusted capital requirements. In contrast to these models, where climate policy amplifies business cycle fluctuations or financial shocks through otherwise conventional channels, our paper explicitly characterizes how exogenous changes to climate policy affect the (potentially sector-specific) conduct of optimal bank capital regulation.

Most closely related to our paper is Carattini, Melkadze, and Heutel (2023), who study the effects of asset stranding on the macroeconomy. Through a financial accelerator mechanism, bank balance sheet losses can render credit supply to all firms in the economy inefficiently low. In their framework, macroprudential policy is represented by direct taxation of sector-specific assets and, when set optimally, mitigates socially inefficient asset stranding. In our framework, asset stranding is not inefficient, since there is no market failure on the corporate loan market: firms always have the option to finance their projects with equity and are not constrained in their real activity by a potential scarcity of bank equity. Instead, the key market failure that gives rise to bank capital regulation stems from inefficiently high bank risk-taking on the deposit market. In that sense, our paper provides a complementary analysis of bank regulation through the lenses of banks' capacity to provide liquid deposits to households rather than banks' capacity to provide credit to different sectors.

Our paper is structured as follows: Section 2 sets up the multi-sector DSGE model with two layers of default. We describe our calibration in Section 3. In Section 4, we discuss the suitability of capital requirements as climate policy instrument. Optimal capital requirements in response to carbon taxes are presented Section 5. Section 7 concludes.

2 Model

Time is discrete and indexed by $t = 1, 2, ...$ The model features a representative household, three types of intermediate good firms, monopolistically competitive final good producers, investment good producers, banks, and a public sector levying carbon taxes and setting bank capital requirements. The intermediate firms produce non-energy, fossil and clean energy goods, respectively. While both energy goods are highly (but not perfectly) substitutable, the elasticity of substitution between energy and non-energy goods is small (but not zero). The final good producer uses both energy goods, the non-energy good, and labor to produce the final consumption good. Investment good firms supply sector-specific investment goods. Banks raise deposits from the representative household to extend loans to all three intermediate good producers.

Households. We keep the household sector intentionally simplistic to maintain a focus on investment and leverage dynamics in the financial and corporate sector. The representative household inelastically supplies $\overline{n}$ units of labor at the real wage w_t. The household derives utility from consumption c_t and from holding end-of-period deposits, d_{t+1}.[9] Deposits held from time $t-1$ to t earn the real interest rate r^D_{t-1}. The household's time discount factor is denoted by β. The maximization

[9]Our results are robust to adding labor supply disutility to the model. However, it is conceptually more straightforward to analyze the key policy trade-off if household welfare solely depends on consumption and deposit holdings.

problem of the representative household is given by

$$V_t = \max_{c_t, d_{t+1}} \frac{c_t^{1-\gamma_C}}{1-\gamma_C} + \omega_D \frac{d_{t+1}^{1-\gamma_D}}{1-\gamma_D} + \beta \mathbb{E}_t \left[V_{t+1} \right] \tag{1}$$
$$\text{s.t.} \quad c_t + d_{t+1} = w_t \overline{n} + (1 + r_{t-1}^D) d_t + div_t + T_t \ ,$$

where div_t collects real dividends from banks and firms. T_t is a lump sum transfer from the government. Solving the maximization problem (1) yields the Euler equation for deposits

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1} (1 + r_t^D) \right] + \omega_D \frac{d_{t+1}^{-\gamma_D}}{c_t^{-\gamma_C}} \ . \tag{2}$$

Here, $\Lambda_{t,t+1} \equiv \beta \frac{c_{t+1}^{-\gamma_C}}{c_t^{-\gamma_C}}$ is the household's stochastic discount factor. Since deposits provide utility to households, the deposit rate r_t^D will be smaller than the risk-free rate r_t implied by the household sdf:

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1} (1 + r_t) \right] \ . \tag{3}$$

Formally, the deposit spread is defined as

$$s_t^{dep} \equiv (1 + r_t^{dep})^4 - (1 + r_t)^4 \ ,$$

which is negative if households value the liquidity services of bank deposits.

Banks. Banks enter period t with liabilities from deposits issued last period $(1+r_{t-1}^D)d_t$ and sector-specific loans l_t^τ granted last period, where $\tau \in \{c, f, n\}$. The bank-specific realized return on the loan portfolio is given by $\mu_t \sum_\tau \mathcal{R}_t^\tau l_t^\tau$ contains two components. First, it depends on sector-specific loan payoffs that are denoted by $\mathcal{R}_t^\tau$ and on (potentially sector-specific) default rates in the non-financial sector (described below). Second, banks are subject to uninsurable idiosyncratic bank risk shocks μ_t, which follow an i.i.d. log-normal distribution with a mean of one and standard deviation ς_μ. These shocks reflect unmodeled limits to diversification of loan portfolios, consistent with empirical findings by Galaasen et al. (2021).

If the idiosyncratic bank risk shock falls below a threshold level $\overline{\mu}_t$, banks are unable to service depositors. In this case, they transfer all their assets and liabilities to the deposit insurance agency (DIA), who covers the shortfall and pays back depositors in full.[10] Put differently, depositors are paid in full by the DIA in the case of bank failure, while banks are protected by limited liability. Banks should be interpreted as all financial institutions that are part of a deposit

[10]Alternatively, one could assume that banks always service deposits but receive a bailout

insurance scheme or enjoy an (implicit) bailout guarantee by the government, see also Begenau (2020).

We follow Clerc et al. (2015) and Mendicino et al. (2018) in assuming that the DIA incurs direct resource losses $T_t^{DIA} = \zeta \cdot F(\overline{\mu}_t) \cdot d_t$ that are proportional to the amount of deposits $F(\overline{\mu}_t)d_t$ under management by the DIA. The threshold realization of the bank risk shock is implicitly given by the return realization $\overline{\mu}_t$ that enables the bank to exactly repay depositors:

$$\overline{\mu}_t = \frac{(1 + r_{t-1}^D)d_t}{\sum_\tau \mathcal{R}_t^\tau l_t^\tau} \; . \tag{4}$$

We assume that banks are restructured intermediately after a failure: they can extend new loans to firms and raise equity and deposits. This facilitates aggregation into representative banks. At the end of period t, the representative bank extends loans l_{t+1}^c, l_{t+1}^f and l_{t+1}^n to clean, fossil and non-energy firms. The loan price depends on firm-specific capital structure choices $q(\overline{m}_{t+1}^\tau)$, described below. The period t dividend of each bank depends on its idiosyncratic shock realization μ_t and is given by

$$div_t^b = \mathbb{1}\{\mu_t > \overline{\mu}_t\} \left(\mu_t \sum_\tau \mathcal{R}_t^\tau l_t^\tau - (1 + r_{t-1}^D)d_t \right) + d_{t+1} - \sum_\tau q(\overline{m}_{t+1}^\tau) l_{t+1}^\tau \; .$$

Banks finance their loan portfolio with deposits d_{t+1} or equity e_{t+1}. In the spirit of Gertler and Kiyotaki (2010), equity can be interpreted as a transfer from households. Crucially, banks can not raise new equity to repay liabilities from legacy deposits.[11] We can define the following balance sheet identity:

$$d_{t+1} + e_{t+1} = \sum_\tau q(\overline{m}_{t+1}^\tau) l_{t+1}^\tau \; . \tag{5}$$

Banks are required to finance a (potentially type-specific) fraction κ_t^τ for $\tau = \{c, f, n\}$ of their assets by equity. When maximizing the present value of dividends,

whenever $\mu_t < \overline{\mu}_t$. In this case, bank dividends are given by

$$div_t^b = \mu_t \sum_\tau \mathcal{R}_t^\tau l_t^\tau - (1 + r_{t-1}^D)d_t + S_t^{DIA} + d_{t+1} - \sum_\tau q(\overline{m}_{t+1}^\tau) l_{t+1}^\tau \; .$$

If the bailout is given by the state-dependent transfer

$$S_t^{DIA} = \mathbb{1}\{\mu_t < \overline{\mu}_t\} \big((1 + r_{t-1}^D)d_t - \mu_t \sum_\tau \mathcal{R}_t^\tau l_t^\tau \big)$$

that exactly covers the shortfall, period t dividends are identical to the formulation using a deposit insurance agency.

[11] The implicit within-period timing assumption is that loan payoffs realize and deposits have to be repaid before the market for equity, deposits and loans going into period $t + 1$ opens.

banks have to satisfy the following constraint:

$$(1+r_t^D)d_{t+1} \leq \sum_\tau (1-\kappa_t^\tau)\mathbb{E}_t\Big[\mathcal{R}_{t+1}^\tau\Big] l_{t+1}^\tau \ . \tag{6}$$

If there would be no bank default risk and no equity requirements ($\kappa_t^\tau = 0$ for all τ), this part of our model reduces to the setup studied in Cúrdia and Woodford (2011), in which banks are required to repay depositors in expectations. Due to the immediate restructuring assumption and the i.i.d. nature of the bank risk shock μ_t, the bank problem reduces to a two-period consideration, which resembles the setup with overlapping generations of financial intermediaries in Clerc et al. (2015):

$$\max_{d_{t+1},\{l_{t+1}^\tau\}} d_{t+1} - \sum_\tau q(\overline{m}_{t+1}^\tau)l_{t+1}^\tau + \mathbb{E}_t\left[\Lambda_{t,t+1}\int_{\overline{\mu}_{t+1}}^\infty \mu_{t+1}\sum_\tau \mathcal{R}_{t+1}^\tau l_{t+1}^\tau - (1+r_t^D)d_{t+1}dF(\mu_{t+1})\right] .$$

Raising deposits increases bank dividends in period t by one unit. This exceeds expected discounted repayment obligations in period $t+1$:

$$\mathbb{E}_t\left[\Lambda_{t,t+1}(1+r_t^D)\big(1-F(\overline{\mu}_{t+1})\big)\right] < 1 \ ,$$

where $F(\overline{\mu}_{t+1}) \equiv \int_0^{\overline{\mu}_{t+1}} dF(\mu_{t+1})$ denotes the bank failure probability. This is due to (i) liquidity benefits of deposits (we obtain $\Lambda_{t,t+1}(1+r_t^D) < 1$ from combining equation (2) and equation (3)) and (ii) the risk of bank failure $(1-F(\overline{\mu}_{t+1}) < 1$ if $\mu_{t+1} > 0)$. This implies that the capital requirement binds in all states (see also Begenau 2020).

Solving the profit maximization problem subject to the binding capital constraint (6), we obtain a loan pricing condition

$$q(\overline{m}_{t+1}^\tau) = \mathbb{E}_t\left[\left\{(1-\kappa_t^\tau)\underbrace{\left(\frac{1}{1+r_t^D} - \Lambda_{t,t+1}\big(1-F(\overline{\mu}_{t+1})\big)\right)}_{\text{Deposit Financing Wedge } \Xi_{t+1}} + \underbrace{\Lambda_{t,t+1}\Big(1-G(\overline{\mu}_{t+1})\Big)}_{\text{Bank-owner sdf } \overline{\Lambda}_{t,t+1}}\right\}\mathcal{R}_{t+1}^\tau\right] . \tag{7}$$

Details are relegated to Appendix A. We refer to the term in curly brackets in Equation (7) as the *bank sdf*. It consists of the benefits of deposit financing Ξ_{t+1}, weighted by the deposit financed loan share $(1-\kappa_t^\tau)$, and the bank-owner sdf $\overline{\Lambda}_{t,t+1}$, where $(1-G(\overline{\mu}_{t+1})) \equiv \int\limits_{\overline{\mu}_{t+1}}^{\infty} \mu_{t+1}dF(\mu_{t+1})$ is the expected bank productivity conditional on not failing.[12]

[12]If banks were fully equity financed ($\kappa_t^\tau = 1$ for all τ), the deposit financing wedge Ξ_t is irrelevant for the loan pricing condition. Furthermore, the bank failure rate would be zero, i.e. the bank-owner sdf coincides with the household sdf. Consequently, the loan pricing condition

The deposit financing wedge shows that both the deposit insurance put and liquidity services affect the pricing of loans via bankers' stochastic discount factor. The deposit financing wedge Ξ_t reflects the benefit of financing a loan through deposits $r_t^D < r_t$ due to their liquidity benefits. It also reflects the deposit insurance put: the expected repayment obligation in period $t+1$ of raising one unit of deposits in period t is only $1 - F(\overline{\mu}_{t+1})$. All else equal, loan prices increase if capital requirements are relaxed, since this allows banks to increase the deposit financed share.

The bank-owner sdf $\overline{\Lambda}_{t,t+1}$ is closely related to the household sdf due to the perfect risk-sharing assumption, but also contains the expected bank profitability, conditional on not failing $(1 - G(\overline{\mu}_{t+1}))$. Since the bank risk shock has a mean of one by assumption, we have $(1 - G(\overline{\mu}_{t+1}) < 1)$. A bank loses control of their assets to the DIA in case it fails. Since they take their own failure probability into account when pricing loans, the expected loan payoff is discounted more heavily if bank failure is more likely. Stringent capital requirements, therefore, also have a positive effect on loan supply by decreasing $(1 - G(\overline{\mu}_{t+1}))$, which resembles the "forced safety effect" studied by Bahaj and Malherbe (2020).

Investment Good Firms. There is a representative producer for each of the three investment goods that intermediate firms acquire at price ψ_t^τ. To produce one unit of each investment good, these firms use $\left(1 + \frac{\Psi_I}{2}\left(\frac{i_t^\tau}{i_{t-1}^\tau}\right)\right)$ units of the final good. The profit maximization problem

$$\max_{\{i_t^\tau\}_{t=0}^\infty} \mathbb{E}_0 \left[\sum_{t=0}^\infty \beta^t \frac{C_t^{-\gamma_C}}{C_0^{-\gamma_C}} \left\{ \psi_t^\tau i_t^\tau - \left(1 + \frac{\Psi_I}{2} \left(\frac{i_t^\tau}{i_{t-1}^\tau} - 1 \right)^2 \right) i_t^\tau \right\} \right]$$

yields the first-order condition for (type-specific) investment good supply

$$\psi_t^\tau = 1 + \frac{\Psi_I}{2} \Big(\frac{i_t^\tau}{i_{t-1}^\tau} - 1 \Big)^2 + \Psi_I \Big(\frac{i_t^\tau}{i_{t-1}^\tau} - 1 \Big) \frac{i_t^\tau}{i_{t-1}^\tau} - \mathbb{E}_t \left[\Lambda_{t,t+1} \Psi_I \Big(\frac{i_{t+1}^\tau}{i_t^\tau} - 1 \Big) \Big(\frac{i_{t+1}^\tau}{i_t^\tau} \Big)^2 \right] .$$

Intermediate Good Firms. Having described the supply of investment goods and bank loans, we now describe the demand for loans and investment goods. There are three types of intermediate good firms. As customary in the literature, we do not allow firms to switch technologies. All three firm types produce a

collapses to a standard consumption-based asset pricing condition $q(\overline{m}_{t+1}^\tau) = \mathbb{E}_t \left[\Lambda_{t,t+1} \mathcal{R}_{t+1}^\tau\right]$, rather than an intermediary asset pricing condition. In contrast, if there are no capital requirements ($\kappa_t^\tau = 1$ for all τ), bank failure rate and deposit supply would be very high. Since we assume that DIA losses are proportional to bank deposits and the household utility function is concave in deposits, it is intuitive that there is an interior solution for κ in steady state.

homogeneous sector-specific intermediate good z_t^τ for $\tau \in \{c, f, n\}$. The non-energy good is denoted by z_t^n, while energy goods z_t^c and z_t^f are produced by a representative clean and fossil firm, respectively. Firms maximize the present value of dividends, discounted by the households' stochastic discount factor, which follows from the perfect risk-sharing assumption. In the main text, we only present the problem of the fossil energy firm and report the first-order conditions of clean energy and non-energy firms in Appendix A.

The production technology is linear in capital and subject to an uninsurable idiosyncratic productivity shock, giving rise to corporate default. As it is standard in the literature, we assume that the shock is i.i.d. log-normally distributed with standard deviation ς_M. We normalize its mean to $-\varsigma_M^2/2$, which ensures that the shock has a mean of one. To finance their investment, firms can either use equity (negative dividends) or long-term loans l_t^τ of which a share $0 < \chi \leq 1$ matures each period. The non-maturing share $(1-\chi)$ is rolled over at the loan price $q(\overline{m}_{t+1}^f)$. Firms default on the maturing share χl_t^f, if revenues from production $p_t^f m_t z_t^f$ fall below the required loan repayment χl_t^f. In this case, banks are entitled to the period t output, but have to pay a restructuring costs φl_t^f. As outlined in Gomes, Jermann, and Schmid (2016), we assume that firms are restructured immediately which, together with the i.i.d. nature of idiosyncratic productivity shocks, permits aggregation into a representative fossil energy firm (see also Giovanardi et al. 2023).

Fossil energy firms are subject to emission taxes τ_t. We follow Heutel (2012) in assuming that unabated emissions are proportional to production and allow fossil firms to undertake a costly abatement effort η_t. Total emissions are therefore given by $e_t = (1-\eta_t)z_t^f$ while the total emission tax payed in period t is given by $\tau_t(1-\eta_t)z_t^f$. Abatement costs are convex in the abatement effort and proportional to output:

$$\Theta(\eta_t, z_t^f) = \frac{\theta_1}{\theta_2+1}\eta_t^{\theta_2+1} z_t^f \ ,$$

with θ_1, $\theta_2 > 0$. The optimal abatement effort is given by

$$\eta_t^* = \left(\frac{\tau_t}{\theta_1}\right)^{\frac{1}{\theta_2}} \ . \tag{8}$$

The carbon tax *compliance cost* per unit of fossil production are obtained from plugging-in the optimal abatement effort η_t^* and summarizes all expenses induced by carbon taxation and abatement:

$$\xi_t \equiv \tau_t \left(1 - \left(\frac{\tau_t}{\theta_1}\right)^{\frac{1}{\theta_2}}\right) + \frac{\theta_1}{\theta_2+1}\left(\frac{\tau_t}{\theta_1}\right)^{\frac{\theta_2+1}{\theta_2}} \ . \tag{9}$$

Compliance costs are increasing in τ_t since we have assumed $\theta_2 > 0$. All else equal, compliance costs increase the break-even productivity shock realization $\overline{m}_t^f$ below which the firm defaults. Fossil energy firms take this into account when making their investment and leverage choices. Combining these elements, we can write dividends as

$$div_t^f = \mathbb{1}\{m_t > \overline{m}_t^f\} \cdot \left((p_t^f - \xi_t)z_t^f - \chi l_t^f\right) - \psi_t^f i_t^f + q_t^f \left(l_{t+1}^f - (1-\chi)l_t^f\right).$$

After plugging in the capital accumulation constraint $i_t^f = k_{t+1}^f - (1-\delta_K)k_t$, the relevant part of the maximization problem becomes

$$\max_{k_{t+1}^f, l_{t+1}^f, \overline{m}_{t+1}^f} -\psi_t^f k_{t+1}^f + q_t^f \left(l_{t+1}^f - (1-\chi)l_t^f\right) + \mathbb{E}_t\Bigg[\widetilde{\Lambda}_{t+1} \cdot \Bigg\{\int_{\overline{m}_{t+1}^f}^{\infty} (p_{t+1}^f - \xi_{t+1}) \cdot m_{t+1} \cdot k_{t+1}^\tau -$$
$$- \chi l_{t+1}^f dF(m_{t+1}) + \psi_{t+1}^f (1-\delta_K)k_{t+1}^f + q(\overline{m}_{t+2}^f)\Big(l_{t+2}^f - (1-\chi)l_{t+1}^f\Big)\Bigg\}\Bigg],$$

subject to the default threshold $\overline{m}_{t+1}^f \equiv \frac{\chi l_{t+1}^f}{(p_{t+1}^f - \xi_{t+1})k_{t+1}^f}$ and subject to the financing conditions given by banks' loan pricing condition (7). In the following, the expected profitability of a defaulting firm is denoted by $G(\overline{m}_t^\tau) \equiv \int_0^{\overline{m}_t^\tau} m dF(m)$ and the default probability is denoted by $F(\overline{m}_t^\tau) \equiv \int_0^{\overline{m}_t^\tau} dF(m)$.

Firms take the effect of their risk choice on loan prices into account when making their loan and investment decisions. The risk choice is linked to the loan price through the expected per-unit payoff:

$$\mathbb{E}_t[\mathcal{R}_{t+1}^f] = \mathbb{E}_t\left[(1-\chi)q(\overline{m}_{t+2}^f) + \chi\left(1 - F(\overline{m}_{t+1}^f) + \frac{G(\overline{m}_{t+1}^f)}{\overline{m}_{t+1}^f} - F(\overline{m}_{t+1}^f)\varphi\right)\right]. \quad (10)$$

The first term reflects the the rollover share $(1-\chi)$ of loans outstanding is valued at market price $q(\overline{m}_{t+1}^f)$. The second term represents the payoff from maturing share χ: it consists of the repayment probability $1 - F(\overline{m}_{t+1}^f)$, the production revenues seized in case of default $\frac{G(\overline{m}_{t+1}^f)}{\overline{m}_{t+1}^f}$, and expected restructuring cost $F(\overline{m}_{t+1}^f)\varphi$.[13]

Firm Loan and Investment Choice. Denoting the Lagrange-multiplier on the default threshold by λ_t^f, the first-order conditions for investment and loan issuance are given by

$$q(\overline{m}_{t+1}^f) - \lambda_t^f \frac{\overline{m}_{t+1}^f}{l_{t+1}^f} = \mathbb{E}_t\left[\Lambda_{t,t+1}\Big(\chi(1 - F(\overline{m}_{t+1}^f)) + (1-\chi)q(\overline{m}_{t+2}^f)\Big)\right], \quad (11)$$

[13] The production revenues banks seize are given by $G(\overline{m}_{t+1}^f)(p_{t+1}^f - \xi_{t+1})k_{t+1}^f$, which are distributed equally among the holders of maturing loans χl_{t+1}^f. Expressing recovered revenues per unit of maturing loans, we obtain the term $\frac{G(\overline{m}_{t+1}^f)}{\overline{m}_{t+1}^f}$.

and

$$\psi_t^f - \lambda_t^f \frac{\overline{m}_{t+1}^f}{k_{t+1}^f} = \mathbb{E}_t \left[\Lambda_{t,t+1} \Big(\psi_{t+1}^f (1-\delta_K) + (p_{t+1}^f - \xi_{t+1}) \big(1 - G(\overline{m}_{t+1}^f)\big) \Big) \right] . \tag{12}$$

while the risk choice $\overline{m}_{t+1}^f$ is determined according to

$$\lambda_t^f - q'(\overline{m}_{t+1}^f) \Big(l_{t+1}^f - (1-\chi) l_t^f \Big) = \Lambda_{t,t+1} \left[\Big(l_{t+2}^f - (1-\chi) l_{t+1}^f \Big) q'(\overline{m}_{t+2}^f) \frac{\partial \overline{m}_{t+2}^f}{\partial \overline{m}_{t+1}^f} \right] . \tag{13}$$

The first-order condition for loans (11) equates the marginal benefit of taking up a loan with its costs. Since the loan maturity exceeds one period, it also contains a dilution term that enters through the multiplier on the risk choice λ_t^f, which is pinned down by equation (13). The cost of marginally increasing loans consist of the redemption share χ, weighted by the repayment probability, and the roll-over part $(1-\chi)$, valued by next period's loan price $q(\overline{m}_{t+2}^f)$. Equation (12) requires that the cost of investment (ψ_t^f) equals its expected discounted payoff, which consists of the value of undepreciated capital next period and expected revenues per unit of capital, conditional on repayment. Per-unit revenues depend on the fossil energy price net of taxes and abatement. Since investment also affects the default probability in future periods, the multiplier on the risk choice also enters the first-order condition for investment.

Final Good Firms. Monopolistically competitive firms aggregate both energy inputs and the non-energy intermediate good together with labor into the final good y_t according to a nested CES-structure (see also Fried, Novan, and Peterman 2022):

$$y_t = A_t \widetilde{z}_t^{\alpha} n_t^{1-\alpha} , \tag{14}$$

with

$$\widetilde{z}_t = \left(\widetilde{\nu} (z_t^e)^{\frac{\widetilde{\epsilon}-1}{\widetilde{\epsilon}}} + (1-\widetilde{\nu}) (z_t^n)^{\frac{\widetilde{\epsilon}-1}{\widetilde{\epsilon}}} \right)^{\frac{\widetilde{\epsilon}}{\widetilde{\epsilon}-1}} , \tag{15}$$

where $\widetilde{\nu}$ is the weight on energy in the intermediate goods bundle and $\widetilde{\epsilon}$ is the elasticity between energy and non-energy goods. The energy bundle is, in turn, given by

$$z_t^e \equiv \left(\nu (z_t^c)^{\frac{\epsilon-1}{\epsilon}} + (1-\nu) (z_t^f)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}} , \tag{16}$$

where ν is the clean energy weight in the energy bundle. Solving the profit maximization problem yields standard demand functions for labor and all intermediate goods

$$\alpha\widetilde{\nu}\nu\frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^e}\right)^{\frac{1}{\widetilde{\epsilon}}}\left(\frac{z_t^e}{z_t^c}\right)^{\frac{1}{\epsilon}} = p_t^c\ , \tag{17}$$

$$\alpha\widetilde{\nu}(1-\nu)\frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^e}\right)^{\frac{1}{\widetilde{\epsilon}}}\left(\frac{z_t^e}{z_t^f}\right)^{\frac{1}{\epsilon}} = p_t^f\ , \tag{18}$$

$$\alpha(1-\widetilde{\nu})\frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^n}\right)^{\frac{1}{\widetilde{\epsilon}}} = p_t^n\ , \tag{19}$$

$$(1-\alpha)\frac{y_t}{n_t} = w_t\ . \tag{20}$$

Furthermore, labor market clearing requires that $n_t = \overline{n}$.

Public Sector and Resource Constraint. The model is closed by assuming that carbon tax revenues and DIA losses are rebated in lump-sum fashion to households ($T_t = \tau_t e_t - T_t^{DIA}$). The resource constraint is given by

$$y_t = c_t + \sum_{\tau} i_t^{\tau}\left(1+\frac{\Psi_I}{2}\left(\frac{i_t^{\tau}}{i_{t-1}^{\tau}}-1\right)^2\right) + \frac{\theta_1}{\theta_2+1}\left(\frac{\tau_t}{\theta_1}\right)^{\frac{\theta_2+1}{\theta_2}} z_t^f + \varphi F(\overline{m}_t) + \zeta F(\overline{\mu}_t) d_t\ , \tag{21}$$

where the abatement costs are evaluated at the optimal abatement effort η_t^*, given the tax rate τ_t. Note that the benefits of higher deposit supply do not enter the resource constraint, but are part of the welfare objective via the household utility function.

3 Calibration

Each period corresponds to one quarter. The aim of our quantitative analysis is not to provide policy recommendations based on a country-specific calibration, but rather to show that the interactions between bank regulation and climate policy hold for a range of reasonable model parameterizations. Most parameters take standard values used in multi-sector DSGE models, while parameters governing financial frictions are set to match moments typically used in the macro banking literature. We describe the parameters associated with each group of agents in turn.

Households and Banks. We fix household's consumption CRRA parameter $\gamma_C = 2$ and labor supply at $\overline{n} = 0.3$. The household discount factor β is set to 0.995, implying an annualized real interest rate of 2%. We set the liquidity curvature parameter in the household's valuation to liquidity services γ_D to 1.5. The weighting parameter $\omega_D = 0.025$ yields a deposit spread of -100bp, which lies in the middle of commonly used targets in the literature, see for example Gerali et al. (2010).

The standard deviation of banks' risk shock $\varsigma_\mu = 0.0275$ implies an annualized bank failure rate of 0.7% matching the data moment used in Mendicino et al. (2020).[14] We set the deadweight loss parameter of the deposit insurance agency to $\zeta = 0.015$, which renders a long run capital requirement of 8% optimal in the Ramsey optimal policy problem. Appendix B.3 shows the macroeconomic effects of long run capital requirements.

Intermediate Good Firms. The quarterly capital depreciation rate is fixed at the standard value of $\delta_K = 0.025$. The baseline calibration assumes symmetric credit frictions (governed by the idiosyncratic productivity shock volatility ς_M) and identical capital requirements across sectors ($\kappa_t^c = \kappa_t^f = \kappa_t^n = \kappa^{sym}$). We set the average loan maturity to five years ($\chi = 0.05$). Similar to the calibration strategy in Giovanardi et al. (2023), we jointly calibrate the standard deviation of idiosyncratic productivity shocks ς_M and the restructuring cost parameter φ to match the corporate default rate and the recovery rate on loans. In the model, the expected *recovery rate per unit of loans* is given by the realized payoff from holding a distressed loan relative to the promised payoff. It is related to the expected productivity of a defaulter, i.e. the expected productivity conditional on defaulting $\frac{G(\overline{m}_t^\tau)}{F(\overline{m}_t^\tau)}$ and the restructuring cost φ, i.e.

$$recov_t^\tau = \frac{G(\overline{m}_t^\tau)}{F(\overline{m}_t^\tau)\overline{m}_{t+1}^f} - \varphi\ . \tag{22}$$

We set $\varphi = 0.6$ to target a recovery rate of 30%, which is in line with the literature (Clerc et al. 2015, Gomes, Jermann, and Schmid 2016 and Corbae and D'Erasmo 2021). Setting the standard deviation of firm productivity shocks to $\varsigma_M = 0.25$ matches an (annualized) corporate default rate of 2%, which lies in the range of typically targeted values: using US data, Gomes, Jermann, and Schmid (2016) and Corbae and D'Erasmo (2021) target a value of 1.6% and 1.8%, respectively, while Clerc et al. (2015) and Mendicino et al. (2021) use European data and target a value of 3% and 2.7%, respectively.[15] Our baseline calibration implies

[14] We provide a robustness analysis of our main policy experiments targeting an annualized failure rate of 2%, which is for example used by Clerc et al. (2015).

[15] Elenev, Landvoigt, and Nieuwerburgh (2021) target a higher value of loan delinquencies of almost 4% p.a., which is based on US data. Recalibrating the model to match a higher corporate default frequency does not materially change our results.

a leverage ratio of 30% at book values, which is trivial to map into our model ($lev_t^\tau = l_t^\tau / k_t^\tau$). The target corresponds to the full sample average reported in Strebulaev and Yang (2013) for publicly traded US firms and is at the lower end of leverage ratios targeted in the literature. Targeting a relatively low leverage ratio is also appropriate in our model: loan financing is only cheaper than equity due to liquidity premia households are paying on bank deposits and our model abstracts from other reasons to issue corporate debt, such as tax advantages.

Table 1: Baseline Calibration

Parameter	**Value**	**Source/Target**
Households		
Household discount factor β	0.995	Standard
Consumption CRRA γ_C	2	Standard
Liquidity curvature γ_D	1.5	In line with Begenau (2020)
Liquidity weight ω_D	0.025	**Target: Deposit spread -100bps**
Labor supply $\overline{n}$	0.3	Standard
Technology		
Inv. adj. parameter Ψ_I	10	Standard
Capital depreciation rate δ_K	0.025	Standard
Cobb-Douglas coefficient α	1/3	Standard
Energy weight $\widetilde{\nu}$	0.0015	Energy share
Energy/non-energy CES $\widetilde{\epsilon}$	0.2	Bartocci, Notarpietro, and Pisani (2022)
Clean weight ν	0.3865	Clean energy share
Fossil/clean CES ϵ	3	Fried, Novan, and Peterman (2022)
Abatement cost parameter θ_1	0.016	Full abatement at 125$/ToC
Abatement cost parameter θ_2	1.6	Heutel (2012)
Financial Markets		
St. dev. bank risk ς_μ	0.0275	**Target: Bank failure rate 0.7%**
St. dev. firm risk ς_m	0.25	**Target: Firm default rate 2%**
Loan maturity parameter χ	0.05	5-year average maturity
Restructuring costs φ	0.6	**Target: Recovery rate 30%**
Deposit insurance loss ζ	0.011	Optimality of κ^{sym}
Capital requirement κ^{sym}	0.08	Basel III
Shocks		
Persistence TFP ρ_A	0.95	Standard
TFP shock st. dev. σ_A	0.005	Standard

Investment and Final Good Producers. The Cobb-Douglas coefficient is fixed at $\alpha = 1/3$. Persistence and standard deviation of the aggregate TFP shock are set to $\rho_A = 0.95$ and $\sigma_A = 0.005$, which are standard values in the business cycle literature. The investment adjustment cost $\Psi_I = 10$ are consistent with the E-DSGE literature (see Annicchiarico, Carli, and Diluiso (2023) and the references therein) and medium scale DSGE models, such as the ECB's area wide model (see Coenen et al. (2019) and the references therein).

The sectoral shares and substitution elasticities crucially determine the effects of carbon taxes and of differentiated capital requirements. In our model, these shares are determined by the weighting parameters $\widetilde{\nu}$ and ν in equation (15) and equation (16), respectively. The elasticity $\widetilde{\epsilon} = 0.2$ between energy and non-energy goods follows Bartocci, Notarpietro, and Pisani (2022) who calibrate a medium scale DSGE model to sectoral data from the EU. The weighting parameter $\widetilde{\nu} = 0.0015$ then implies an energy share of 10% in the final good production, which is also used as a calibration target in Bartocci, Notarpietro, and Pisani (2022). We set $\nu = 0.3865$ to target a clean energy sector size of 20%. As in Fried, Novan, and Peterman (2022), we fix the elasticity between clean and fossil energy at $\epsilon = 3$. The weighting and curvature parameters of abatement costs are set to $\theta_1 = 0.0335$ and $\theta_2 = 1.6$. While the curvature parameter is a standard value in the literature (Heutel 2012), the weight implies full abatement for any carbon tax exceeding 125\$/ToC. This value is in the range of net-zero carbon taxes implied by similar models, such as Ferrari and Nispi Landi (2023). The parameterization is summarized in Table 1.

Table 2: Model Fit: Untargeted Moments

Moment	**Model**	**Data**	**Data Moment Source**
Relative vol. consumption $\sigma(c)/\sigma(y)$	0.77	0.85	Coenen et al. (2019)
Relative vol. investment $\sigma(i)/\sigma(y)$	1.75	2.53	Coenen et al. (2019)
Firm default-GDP $cor(y, F(\overline{m}))$	-0.33	-0.55	Kuehn and Schmid (2014)
Emissions-GDP $cor(y, e)$	0.73	0.64	Khan et al. (2019)

Notes: Higher-order moments are computed under the assumption that total factor productivity A_t in (14) follows an AR(1)-process in logs with persistence $\rho_A = 0.95$ and standard deviation $\sigma_A = 0.005$.

Table 2 presents the model's ability to reconcile second moments typically used in the macro-finance and macro-banking literature. Specifically, the model implies a countercyclical default probability in the corporate sector, which plays a crucial role for dynamic bank capital regulation. The pro-cyclicality of emissions is based on US data (Khan et al. 2019) and is captured well by the model.

4 Bank Regulation as Climate Policy Instrument

In this section, we use our calibrated model to study the implications of differentiated capital requirements as climate policy instrument. Due to the long run nature of climate policy objectives, we focus on a comparison of long run means in this section. Table 3 summarizes the implications of increasing the capital requirement on fossil loans to $\kappa^f = 0.12$, which corresponds to the current risk-weight of 150% applied to loans rates BB- or lower.[16] As the second column of Table 3 shows, tilted bank regulation has an impact on emissions. By reducing the weight of the deposit financing wedge for fossil loans $(1 - \kappa_t^f)$, debt financing becomes more costly for fossil energy firms: their loan rate increases from 124bps to 128bps, a value in line with the empirical analysis provided by Thomä and Gibhardt (2019). By their first-order condition for $\overline{m}_{t+1}$, they permanently reduce leverage and investment.

Due to an equilibrium effect operating through intermediate goods demand by the final producer, equations (17) to (19), this policy also has effects on other production sectors. Setting $\kappa^f = 0.12$ makes deposit more valuable to households, such that the deposit spread over the risk-free rate increases. It follows from the first-order condition for loan supply that the loan pricing schedule for clean and non-energy firms shifts outwards. Those firms (slightly) increase their leverage ratio in response, which ultimately translates into higher long run default rates in the clean and non-energy sector.

Table 3: Long Run Effects of Selected Policies

Moment	Baseline	$\kappa^f = 0.12$	$\kappa^f = 0.12 - \eta_t$	1$ tax
Fossil Capital Share	80.00%	79.94%	79.97%	79.80%
Abated Emissions	0	0	2.69%	4.82%
Δ Emissions	-	-0.08%	-2.72%	-5.23%
Bank Failure Prob	0.7%	0.2%	0.5%	0.7%
Deposit Spread	-92bp	-94bp	-93bp	-92bp
Clean Leverage	30.0%	30.1%	30.1%	30.1%
Fossil Leverage	30.0%	30.0%	30.0%	30.1%
Clean Default	2.05%	2.09%	2.06%	2.05%
Fossil Default	2.05%	1.96%	2.01%	2.05%

The effect on the fossil capital share (within the energy sector) is hardly relevant at a macroeconomic level, which declines from 80% to 79.94%. To put this effect into perspective, it is helpful to compare the climate effects of differentiated capital requirements to carbon taxes.[17] Implementing a carbon tax of 1$ per tonne of

[16] Since firms can only use equity and loan financing in our model, it is not necessarily well suited to study very drastic changes to fossil capital requirements, such as the extreme case of 100%.

[17] The model-implied carbon tax is converted into $/ToC following Carattini, Melkadze, and Heutel (2023): we convert model units of output ($y^{model} = 0.801683$ in the baseline calibration) to

carbon (ToC) yields a slightly smaller fossil capital share (79.80%), while the emission reduction is much larger (-5.23%). The reason for this stark difference is that capital requirements do not affect firms' incentive to abate emissions. Instead, size and capital holdings of fossil energy firms decline, but the emission of fossil firms intensity remains unchanged. At the same time, this policy does not have an affect on leverage and default probabilities in the non-financial sector. This essentially rules out capital requirements as a suitable climate policy instrument.

Sustainability-Linked Capital Requirements. In our baseline model, the efficacy of capital requirements as climate policy instrument is very limited since capital requirements do not enter the first-order condition for abatement. Thus, they only affect emissions by reducing the fossil capital share. Increasing capital requirements on fossil loans resembles divestment strategies, since fossil energy firms have to finance a larger share of their investment using costly equity.

Therefore, we allow the capital requirement on fossil loans to depend on the abatement effort undertaken by fossil firms. Such a dependency can in principle take arbitrary forms, but we focus on a simple linear relationship $\kappa_t^f = \widetilde{\kappa} - \eta_t$ for illustrative purposes. Furthermore, we set the carbon tax to zero in this extension to maintain tractability.

$$q(\overline{m}_{t+1}^{\tau}) = \mathbb{E}_t\Big[\big(\big(1-(\widetilde{\kappa}-\eta_t)\big)\Xi_{t+1} + \overline{\Lambda}_{t,t+1}\big)\mathcal{R}_{t+1}^{\tau}\Big] \,. \tag{23}$$

In this setting, the optimal abatement effort depends on the loan pricing condition and the abatement cost function:

$$\eta_t = \left(\mathbb{E}_t\Big[\Xi_{t+1}\mathcal{R}_{t+1}^f\Big]\frac{l_{t+1}^f - (1-\chi)l_t^f}{\theta_1 z_t^f}\right)^{1/\theta_2} \tag{24}$$

As in the baseline case, η_t decreases in the cost function slope parameter θ_1. In addition, it also depends on several expressions reflecting financial frictions in the firm and banking sector. The abatement effort is increasing in the deposit financing wedge, since a large wedge makes the loan price more elastic with respect to capital requirements and, thus, the abatement effort. Using the (aggregate) production function for the fossil sector ($z_t^f = k_t^f$), the abatement effort also depends positively on the expression $\chi\frac{l_{t+1}^f-(1-\chi)l_t^f}{\theta_1 k_t^f}$. This term is related to the share of loans that have to be rolled over each period (χ in steady state) and the relevance of debt

world GDP ($y^{world} = 105$ trillion USD in 2022, at PPP, see IMF 2022). We furthermore convert model emissions ($e^{model} = 2.24941$ in the baseline calibration) into world emissions ($e^{world} = 33$ gigatonnes in 2022). The model-implied carbon price is given by $p^{\text{carbon}} = \frac{y^{\text{world}}/y^{\text{model}}}{e^{\text{world}}/e^{\text{model}}}\tau$ \$/ToC.

financing conditions (the leverage ratio $\frac{l}{k}$ in steady state). Furthermore, the (per-unit) *compliance cost* are now given by $\xi_t = \frac{\theta_1}{\theta_2+1}(\eta_t^*)^{\theta_2+1}$ due to the assumption of zero taxes.

The third column of Table 3 shows the macroeconomic and sectoral effects of sustainability-linked capital requirements. As before, we set $\widetilde{\kappa} = 0.12$. The optimal abatement effort turns out to be 2.69%, such that the fossil capital requirement is around 9.5%. The sectoral re-allocation is smaller than in the case of a simple fossil penalizing factor, but there is a considerable reduction in emissions. This analysis suggests that sustainability-linked capital requirements are more powerful than penalizing factors, their magnitude is still rather small.

5 Optimal Bank Regulation and Carbon Taxes

In the previous section, we have shown that differentiated bank capital requirements have a negligible effect on emissions. In this section, we study how *optimal* bank regulation is affected by a more suitable climate policy instrument: carbon taxes. Specifically, we use our baseline model to study the sectoral and macroeconomic effects of a gradually increasing carbon tax and its implications for optimal bank capital regulation.[18] We impose a linear transition path from a carbon tax of zero to 10\$/ToC that takes 40 quarters and solve the model non-linearly under perfect foresight.[19] Thus, the shift towards a more stringent climate policy is unanticipated, but all uncertainty about its path is resolved immediately.

In our model, costly abatement is the only way for fossil energy firms to reduce emissions without downsizing their assets.[20] The relative compliance cost ξ_t/p_t^f, which measure the policy-induced wedge for fossil energy firms, increase from zero to almost four percent. This implies a 20% share of abated emissions and reduces the expected payoff from fossil investment. As the second row of Figure 1

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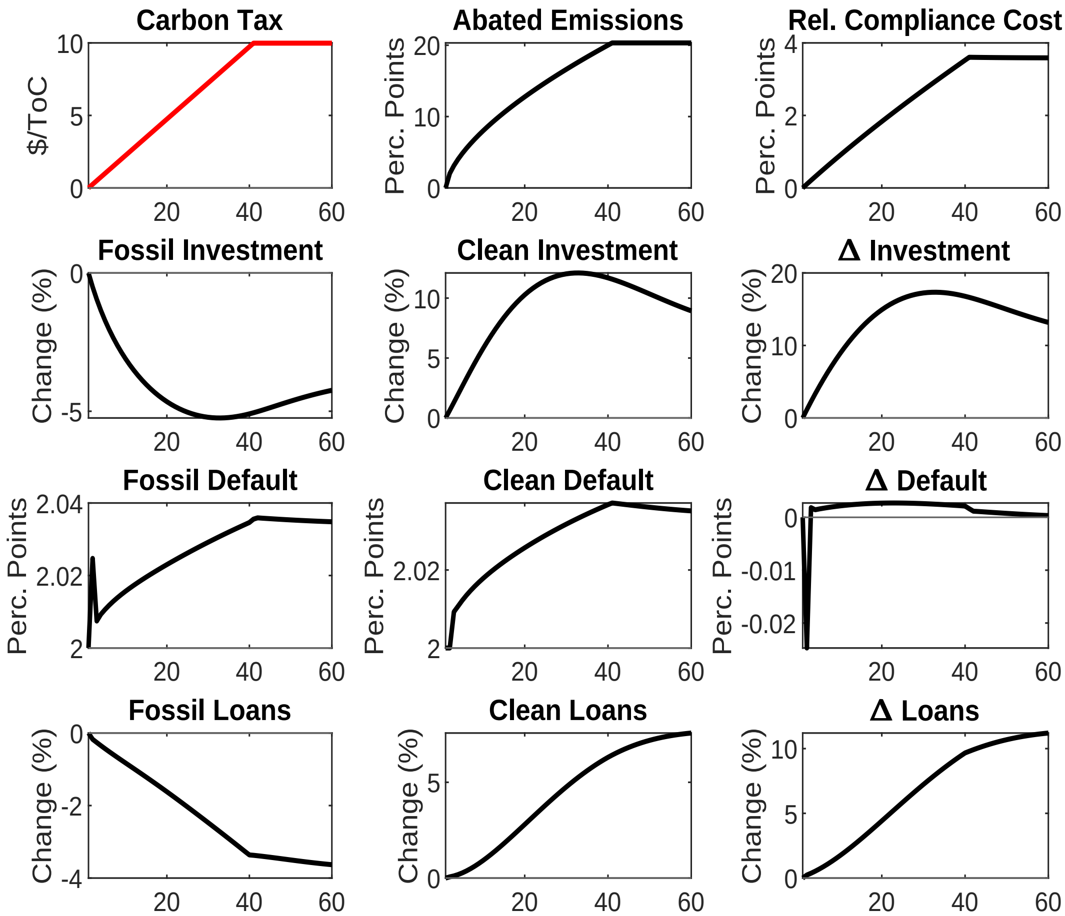
[18] Throughout the analysis, we focus on the interactions of climate policy and bank regulation and abstract from physical risk. Note that it is possible to re-interpret our multi-sector model as sectors that are more and less susceptible to physical risk, respectively. As far as physical risk can be interpreted as sector- or region-specific productivity shock, our optimal policy results carry over to the case of physical risk.

[19] Both the ultimate tax rate and length of the transition period are exogenously set, i.e. they do not emerge from a climate policy trade-off. While a horizon of 10 years appears plausible given current climate policy goals set by many countries, the tax rate of 10\$/ToC enables us to compare our sectoral effects to the empirical analysis of D'Arcangelo et al. (2023).

[20] Our model does not feature technological *change* or technology *choice*. The elasticity and weighting coefficients in the final good technology (16) and (15) are fixed and fossil firms are not allowed to adopt the clean technology, for example by paying a fixed adoption cost. By assuming away these adjustment margins, our model essentially provides a conservative estimate for the financial market effects of the clean transition, since it implicitly forces the fossil sector to operate its less productive capital stock.

shows, this policy induces a substantial shift from fossil towards clean investment. Specifically, the clean sector increases its investment by around 10%, which is in line with empirical findings at the firm level reported in D'Arcangelo et al. (2023). Thus, carbon taxes directly affect the sectoral composition of the intermediate good sector. Apart from a slight overshooting of the relative investment share, the shift towards the clean sector is monotonic. As shown in the lower panel of Figure 1, the sectoral response of loans closely resembles the response of investment.

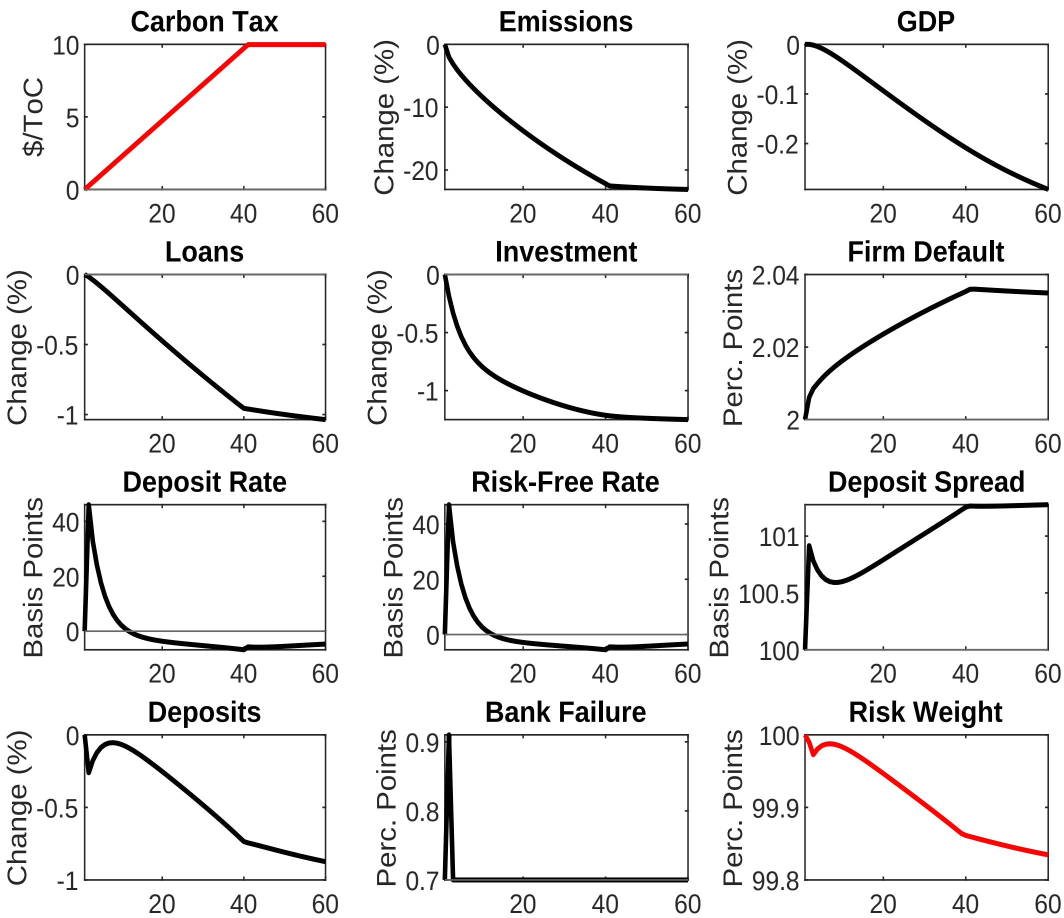
Figure 1: Transition Path, Fossil and Clean Sectors



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. The right plot in each row shows the difference between clean and fossil sector variables.

The response of sector-specific default risk is more nuanced. We can distinguish between *impact* and *short run* effects. In the announcement period, the default threshold of fossil firms ($\overline{m}^f_{t+1} \equiv \frac{\chi l^f_{t+1}}{(p^f_{t+1}-\xi_{t+1})k^f_{t+1}}$) increases due to the unexpected increase in compliance cost ξ_{t+1}. In the baseline calibration, their default rate increases on impact. By contrast, there is a slight drop in the default rate of clean firms: intermediate good firms substitute away from fossil energy, which increases the price of clean energy and, thereby, also the clean default threshold. Once firms can adjust their loan issuance and investment in the short run, their default rates are tied to their risk-choice, which is in turn determined by the relative attractiveness of debt financing, i.e. the benefits of taking up loans and banks' loan supply. Here, we observe that risk-taking in the clean sector is stronger than in the fossil sector. Notably, such a differentiated risk-taking response is not associated with a market failure: the cost of default are fully reflected in the loan pricing condition Equation (7).

Figure 2: Transition Path, Macro Side



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. Ramsey-optimal capital requirements are expressed as "risk-weights" relative to the long run optimal capital requirement of 8%.

Loan market outcomes are nevertheless relevant for optimal bank regulation, since they also have an effect on *aggregate* bank balance sheets and, thereby, on deposit supply. How does a sector-specific shock affect aggregate outcomes? Intermediate goods are imperfectly substitutable in the final good production technology (14). The negative shock to the profitability of fossil energy firms is, thus, recessionary: GDP, investment and loan demand fall (see the first two rows in Figure 2). Since loans are supplied by a perfectly diversified banking sector, aggregate deposits decline as well, such that deposits become more scarce and the deposit spread widens. From the loan pricing condition (7) we observe that banks transmit this decrease in funding cost to firms via the corporate loan market: the relative attractiveness of debt financing increases *for all firms*. By the first-order condition for leverage (13), firms take more risk, which is reflected in a larger corporate default rate. Lastly, after a large increase on impact, the bank failure rate immediately returns to its initial level, since capital requirements are binding in all states.

How do these macroeconomic effects shape the optimal path of bank capital requirements? First, note that all impact responses are a bygone from the regulator's point of view. Changing capital requirements on impact does not affect current bank failure and corporate default rates, since leverage decisions have been made prior to the announcement of the clean transition. Along the transition, the elevated scarcity of bank deposits has an effect on *aggregate* risk-taking by the non-financial sector, which enters the welfare objective through elevated resource losses of corporate default. This channel is, thus, fully reflected in optimal bank capital regulation. However, bank regulation can not improve on the competitive equilibrium allocation as far as *sector-specific* risk-taking is concerned: loan prices fully reflect the future path of carbon taxes and firms' investment decision is optimal, taken loan prices and the return on investment as given.

In addition to the adverse effects of deposit scarcity on firm risk-taking, bank regulation addresses their direct effects on household welfare. Since deposits contract in a relatively stable manner along the transition path, optimal capital requirements decline in a similarly stable fashion to a lower long run level as well. This is consistent with the aggregate risk-taking effects and the optimal response of bank capital regulation in a steady state comparison, which we report in Appendix B.3. In contrast, Appendix B.1 demonstrates that the impact and short run effects of the transition and its implications for bank capital regulation closely resemble the effects of carbon tax shocks.

6 Extensions

This section presents two extensions of our baseline model. Section 6.1 introduces an extreme form of carbon concentration in bank portfolios by introducing sector-specific banks, which gives rise to sector-specific capital requirements. Section 6.2 demonstrates that adding nominal rigidities break the monotonicity of the optimal path of bank capital regulation along the transition.

6.1 Carbon Concentration in Bank Portfolios

A notable implication of our baseline model is the symmetric adjustment of capital regulation in response to carbon taxes. The key to this result is the assumption that banks are perfectly diversified across sectors: the decline in loan demand affects banks uniformly. When banks are not perfectly diversified across sectors, banks with a large exposure to the fossil energy sector are more affected by carbon taxes and will experience a much stronger reduction in their deposit provision than banks with a small exposure. The 2022 ECB Banking Supervision climate risk stress test has revealed a substantial heterogeneity of banks' exposure to the fossil energy sector. A summary of relevant findings is available under this link. See also the discussion of risks associated with highly concentrated bank portfolios in European Banking Authority (2022).

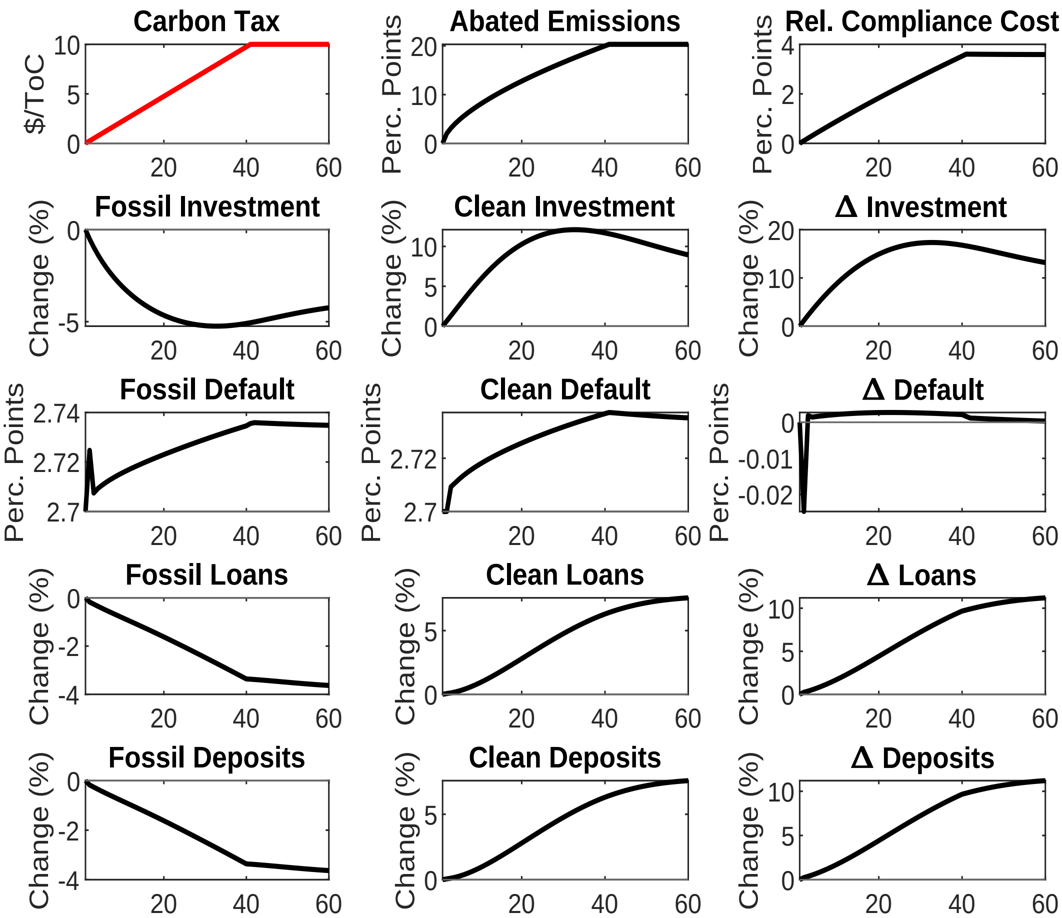
Carbon concentration in the banking sector is difficult to model in a parsimonious way. Therefore, we take an extreme approach and assume that there are three types of banks (clean, fossil, non-energy) that extend loans to the respective intermediate good firms. Notably, this approach necessarily overestimates carbon concentration in bank portfolios, such we can interpret its implications for bank regulation as conservative estimates.

Each (representative) sector-specific bank extends deposits d_t^τ to households. For simplicity, we assume that deposits of each bank are perfectly substitutable. Thus, only aggregate deposits d_t are relevant for households' valuation of liquidity services and the deposit market clearing condition becomes $d_t = d_t^c + d_t^f + d_t^n$. The bank failure thresholds are sector specific and given by $\overline{\mu}_t^\tau = \frac{\mathcal{R}_t^\tau l_t^\tau}{(1+i_{t-1}^D)d_t^\tau}$ for $\tau \in \{c, f, n\}$. Solving the profit maximization problem yields the following loan pricing schedule:

$$q(\overline{m}_{t+1}^\tau) = \mathbb{E}_t\left[\left\{(1-\kappa_t^\tau)\underbrace{\left(\frac{1}{1+r_t^D} - \Lambda_{t,t+1}\big(1 - F(\overline{\mu}_{t+1}^\tau)\big)\right)}_{\text{Deposit Financing Wedge } \Xi_{t+1}^\tau} + \underbrace{\Lambda_{t,t+1}\Big(1 - G(\overline{\mu}_{t+1}^\tau)\Big)}_{\text{Bank-owner sdf } \overline{\Lambda}_{t,t+1}^\tau}\right\}\mathcal{R}_{t+1}^\tau\right]. \tag{25}$$

Different to the baseline case (7), the bank failure probability is sector-specific, such that both the deposit financing wedge Ξ_t^τ and the bank-owner sdf $\overline{\Lambda}_{t,t+1}^\tau$ are sector-specific as well and depend on climate policy. Figure 3 shows the same sector-specific response variables as the baseline and, furthermore, demonstrates in the lower panel that the transition has sector-specific effects on deposit supply, which mirror the responses in the loan market.

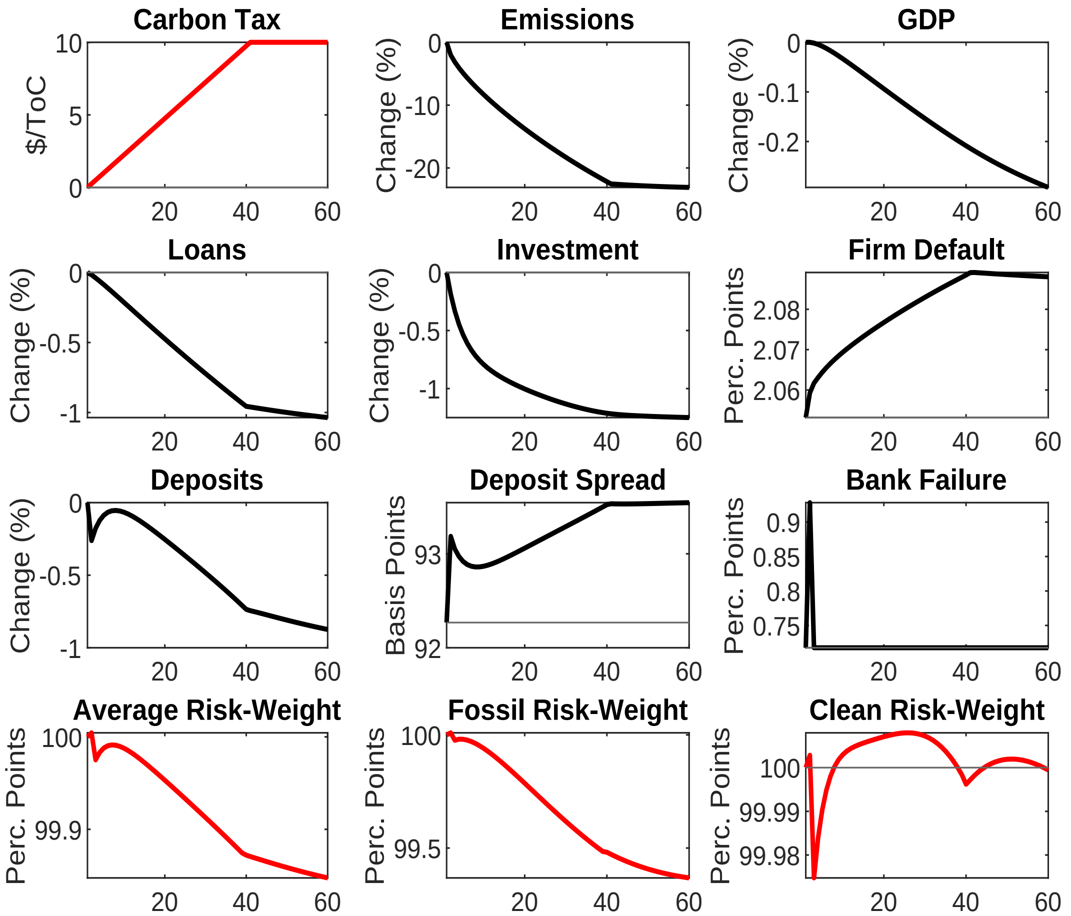
Figure 3: Transition Path with Sector-Specific Banks, Fossil and Clean Sectors



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. The right plot in each row shows the difference between clean and fossil sector variables.

To ensure that the long run bank equity requirement of $\kappa^{sym} = 0.08$ solves the Ramsey optimal policy problem, we slightly increase the DIA loss parameter to $\zeta = 0.0155$. Compared to the baseline case, the lower panel of Figure 4 shows that the *aggregate* bank failure rate reacts more strongly to the transition due to the lack of sectoral diversification. The optimal response is presented in the lower panel of Figure 4. In contrast to the baseline case of perfectly diversified banks, capital regulation now responds heterogeneously across sectors. While the dirty capital requirement relaxes monotonically to counter the adverse effect of deposit supply by fossil banks, it temporarily increases for clean banks, since these banks are supplying an inefficiently large amount of deposits. Since deposits of all sector-specific banks are perfect substitutes, the aggregate response of bank capital regulation has a very similar shape to the baseline. In the long run, it declines to an aggregate risk-weight of 99.85%, which is quite similar to the diversified baseline.

Figure 4: Transition Path with Sector-Specific Banks, Macro Side



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. Ramsey-optimal capital requirements are expressed as "risk-weights" relative to the long run optimal capital requirement of 8%.

6.2 Nominal Rigidities

The baseline model discussed in the previous section implies that optimal bank capital requirements decrease monotonically to a permanently lower level, as carbon taxes gradually increase. In this section, we extend our baseline model with nominal rigidities, which breaks the monotonicity of the path of capital requirements. Specifically, all financial assets (deposits and loans) are denominated in nominal terms. The relevance of (long term) nominal debt in the presence of default risk has been stressed in Gomes, Jermann, and Schmid (2016).

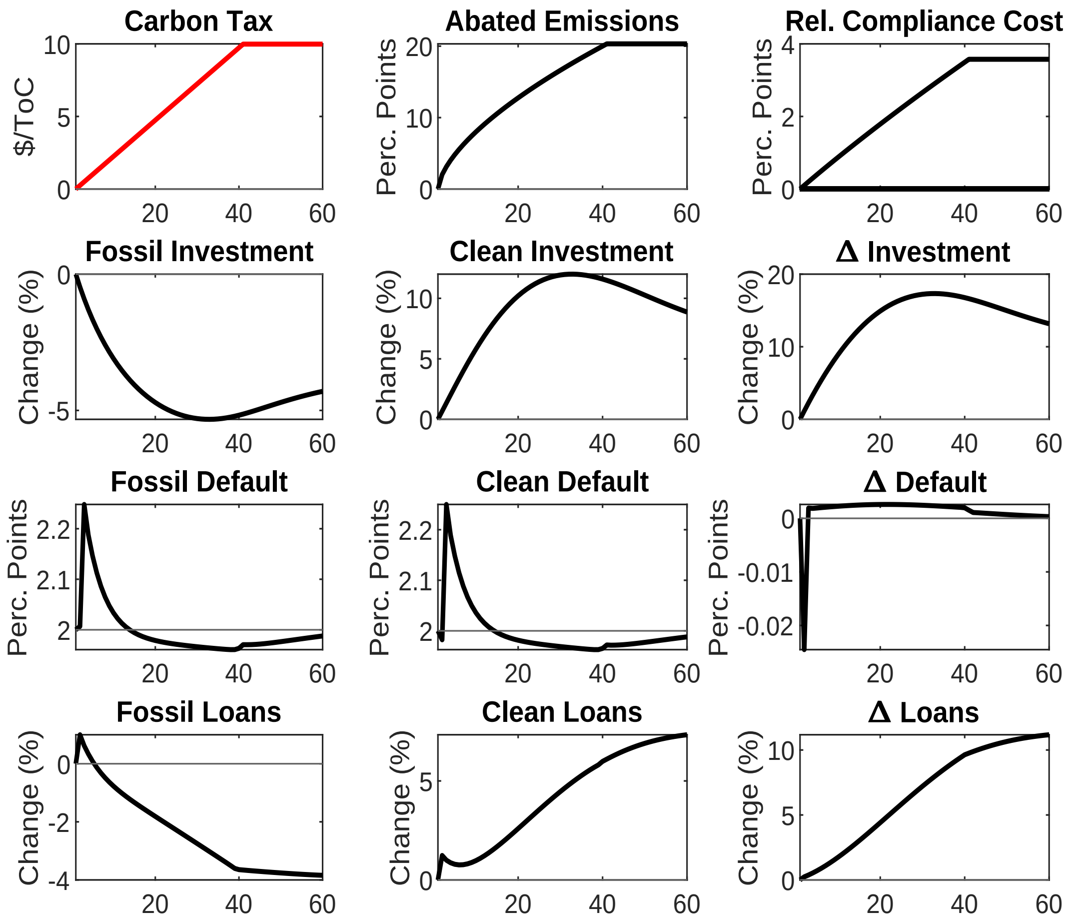
To make the nominal denomination of debt welfare-relevant, we introduce nominal rigidities following the New Keynesian literature. Specifically, final good producers are monopolistically competitive and set their prices subject to Rotemberg price adjustment cost. In Appendix A.2, we show in detail how nominal rigidities enter the equilibrium conditions of our model. We calibrate parameters governing nominal rigidities (final good CES $\phi = 3.8$ and price adjustment cost $\Psi_P = 71.5$) and the monetary policy response (φ_π) based on values reported in the ECB's New Area Wide Model II (Coenen et al. 2019).

Figure 5 reveals that the sectoral effects are very similar to the baseline model. Specifically, the differential response of investment, default risk, and loans exhibits almost the same pattern as in Figure 1. Notably, default risk increases for both sectors in the short-run, which is an implication of the nominal denomination of bank loans and the inflationary impact of carbon taxes: consistent with empirical findings in Ciccarelli and Marotta (2021), the transition is inflationary in the short run, see the bottom middle panel of Figure 6.

In our model, clean and fossil energy is aggregated into an energy bundle using a technology with a high elasticity of substitution, see equation (16).The energy bundle is then combined with the non-energy good under a technology with a very low elasticity of substitution, see equation (15). Taken together, this implies that energy prices increase sharply at the onset of the transition while energy share in the production is comparatively unresponsive.[21] Since debt is denominated in nominal terms, this incentivizes firms across all sectors to issue more debt in real terms. Likewise, the real supply of deposits increases briefly, which induces the deposit spread to decline by around 2 basis points. The optimal response

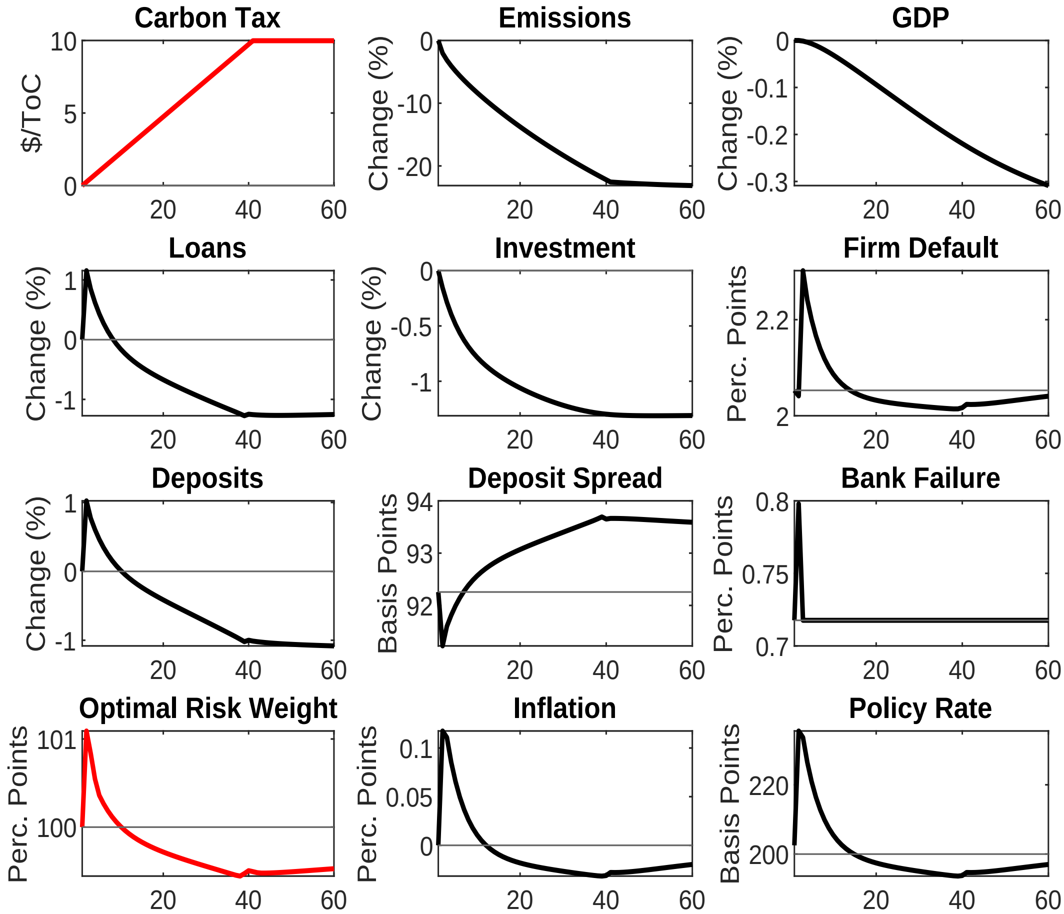
[21] This pattern also arises in the multi-sector model proposed by Coenen, Lozej, and Priftis (2023). Different to such a three-sector setup, Ferrari and Nispi Landi (2023) use a two-sector model with "green" (non-polluting) and brown ("polluting") intermediate goods that are produces with sector-specific labor and aggregated with an elasticity of substitution larger one. Consequently, their model predicts a decline in inflation during the transition which is associated with a large negative aggregate demand effect. Indeed, it is possible to attenuate the inflationary impact of the transition in our model by increasing the elasticity of substitution between non-energy and energy goods above one. However, since our model does not feature sector-specific labor, the model still predicts a moderately inflationary effect of carbon taxes.

Figure 5: Transition Path with Nominal Rigidities, Fossil and Clean Sectors



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. The right plot in each row shows the difference between clean and fossil sector variables.

Figure 6: Transition Path with Nominal Rigidities, Macro and Optimal Bank Regulation



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10\$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. Ramsey-optimal capital requirements are expressed as "risk-weights" relative to the long run optimal capital requirement of 8%.

of bank regulation is presented in the lower panel of Figure 6. In contrast to the baseline case, bank capital regulation tightens over the initial part of the transition, consistent with the temporary uptake in inflation. As soon as the inflationary pressure releases, the optimal path of bank capital regulation resembles the real version of the model.

7 Conclusion

In this paper, we have proposed a multi-sector DSGE model with two layers of default to study optimal capital regulation and climate policy in a joint framework. We show that differentiated capital requirements for clean and fossil loans have a quantitatively negligible effect on carbon emissions even if they depend on fossil firms' abatement effort, rendering them an ill-suited instrument to initiate a transition to net zero. The model also provides a useful laboratory to study implications of the clean transition for optimal bank capital regulation. We show that optimal bank capital requirements are relaxed along the clean transition to counter negative deposit supply effects. In our baseline model without nominal rigidities and perfectly diversified banks, this relaxation is monotonic and symmetric across sectors.

With nominal rigidities, the clean transition is inflationary in the short run: firms have an incentive to increase their leverage, since loans are denominated in nominal terms. Bank regulation tightens in the short run before it is relaxed to a more lenient long run level. If banks are not diversified across sectors, there is scope for differentiated capital requirements: to counter strong negative deposit supply effects of banks that are highly exposed to the fossil sector, bank capital regulation is temporarily tighter on clean banks before converging to a symmetric, lenient long run level: the optimal path of bank regulation is not symmetric across sectors. Our results imply that an understanding of the effects of carbon taxes on price stability and improving the knowledge about the diversification of banks across sectors, for example through climate stress tests, are in important prerequisite for optimal bank regulation along the clean transition.

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A Model Appendix

This section provides additional analytical steps to derive banks' loan supply as well as firms' loan demand and investment. In Appendix A.2, we show all equilibrium conditions that are affected by nominal rigidities.

A.1 Baseline: Bank and Firm FOCs

The profit maximization problem of the representative bank is given by

$$\max_{\{l^\tau_{t+1}\}} \frac{\sum_\tau (1-\kappa^\tau_t)\mathbb{E}_t[\mathcal{R}^\tau_{t+1}]l^\tau_{t+1}}{1+r^D_t} - \sum_\tau q(\overline{m}^\tau_{t+1})l^\tau_{t+1}$$
$$+ \mathbb{E}_t\left[\Lambda_{t,t+1}\int_{\overline{\mu}_{t+1}}^{\infty} \mu_{t+1}\sum_\tau \mathcal{R}^\tau_{t+1}l^\tau_{t+1} - (1-\kappa^\tau_t)\mathbb{E}_t[\mathcal{R}^\tau_{t+1}]l^\tau_{t+1} dF(\mu_{t+1})\right],$$

where we already plugged in the binding bank equity constraint (6). Taking FOC w.r.t. l^τ_{t+1}, we get

$$\frac{(1-\kappa^\tau_t)\mathbb{E}_t[\mathcal{R}^\tau_{t+1}]}{1+r^D_t} - q(\overline{m}^\tau_{t+1}) + \mathbb{E}_t\left[\Lambda_{t,t+1}\left\{(1-G(\overline{\mu}_{t+1}))\mathcal{R}^\tau_{t+1} - (1-F(\overline{\mu}_{t+1}))(1-\kappa^\tau_t)\mathcal{R}^\tau_{t+1}\right\}\right] = 0\,.$$

Rearranging for $q(\overline{m}^\tau_{t+1})$ yields equation (7). The derivative of the loan price (7) with respect to the risk choice is thus given by

$$q'(m^\tau_{t+1}) = \mathbb{E}_t\left[\left((1-\kappa^\tau_t)\Xi_t + \overline{\Lambda}_{t,t+1}\right)\left(-\chi\frac{G(\overline{m}^\tau_{t+1})}{(m^\tau_{t+1})^2} - \chi\varphi F'(\overline{m}^\tau_{t+1}) + (1-\chi)\frac{\partial \overline{m}^\tau_{t+2}}{\partial \overline{m}^\tau_{t+1}}q'(m^\tau_{t+2})\right)\right]\,. \tag{A.1}$$

Following Gomes, Jermann, and Schmid (2016), we pin down $\frac{\partial \overline{m}_{t+2}}{\partial \overline{m}_{t+1}}$, which is an object that depends on the unknown policy function for risk choice, by using an additional condition. Note that this can be obtained by further differentiating one first order condition with respect to $\overline{m}_{t+1}$. From (11), we get an expression for the Lagrangian multiplier:

$$\lambda^\tau_t = \frac{l^\tau_{t+1}}{\overline{m}^\tau_{t+1}}q(\overline{m}^\tau_{t+1}) - \Lambda_{t,t+1}\frac{l^\tau_{t+1}}{\overline{m}^\tau_{t+1}}\left[\chi(1-F(\overline{m}^\tau_{t+1})) + (1-\chi)q(\overline{m}^\tau_{t+2})\right] \tag{A.2}$$

A.2 Extension with Nominal Rigidities

Final Good Firms. As customary in the New Keynesian model, we assume that final goods producers are monopolistically competitive. They sell their differentiated good with a markup over their marginal costs, subject to quadratic price adjustment cost, proportional to the nominal value of sales:

$$ac_t(i) = \frac{\Psi_P}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)^2 P_t y_t \ . \tag{A.3}$$

The cost minimization problem yields the following standard first-order conditions

$$mc_t \alpha \widetilde{\nu} \nu \frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^e}\right)^{\frac{1}{\widetilde{\epsilon}}}\left(\frac{z_t^e}{z_t^c}\right)^{\frac{1}{\epsilon}} = p_t^c \ , \tag{A.4}$$

$$mc_t \alpha \widetilde{\nu}(1-\nu) \frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^e}\right)^{\frac{1}{\widetilde{\epsilon}}}\left(\frac{z_t^e}{z_t^f}\right)^{\frac{1}{\epsilon}} = p_t^f \ , \tag{A.5}$$

$$mc_t \alpha (1-\widetilde{\nu}) \frac{y_t}{\widetilde{z}_t}\left(\frac{\widetilde{z}_t}{z_t^n}\right)^{\frac{1}{\widetilde{\epsilon}}} = p_t^n \ , \tag{A.6}$$

$$mc_t (1-\alpha)\frac{y_t}{n_t} = w_t \ , \tag{A.7}$$

where mc_t is the real marginal cost of production for the final good.

Denoting with ϕ the elasticity of substitution across final goods, final good monopolists face price rigidities à la Rotemberg, with Ψ_P being the parameter governing the degree of nominal rigidity. The price-setting maximization problem of final good producer i is then given by

$$\max_{\{P_t(i)\}_{t=0}^{\infty}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \frac{c_t^{-\gamma_C}}{c_0^{-\gamma_C}} \left\{\left(\frac{P_t(i)}{P_t}\right)^{-\phi}\left(\frac{P_t(i)}{P_t} - mc_t\right) y_t - \frac{\Psi_P}{2}\left(\frac{P_t(i)}{P_{t-1}(i)}\right)^{-\phi}\left(\frac{P_t(i)}{P_t} - 1\right)^2 y_t\right\}\right] .$$

Solving the maximization problem and imposing symmetry, we arrive at the standard New Keynesian Philips curve

$$\mathbb{E}_t\left[\Lambda_{t,t+1}\frac{y_{t+1}}{y_t}\left(\pi_{t+1}-1\right)\pi_{t+1}\right] + \frac{\phi}{\Psi_P}\left(\mathrm{mc}_t - \frac{\phi-1}{\phi}\right) = \left(\pi_t - 1\right)\pi_t \ .$$

Banks. With nominal rigidities, real bank dividends are given by

$$div_t^b = \mathbb{1}\{\mu_t > \overline{\mu}_t\}\left(\mu_t \sum_\tau \mathcal{R}_t^\tau l_t^\tau - (1+r_{t-1}^D)\frac{d_t}{\pi_t}\right) + d_{t+1} - \sum_\tau q(\overline{m}_{t+1}^\tau) l_{t+1}^\tau \ .$$

The bank failure threshold is defined with respect to the real loan payoff and real deposit repayment obligations $\overline{\mu}_t = \frac{(1+r^D_{t-1})\frac{d_t}{\pi_t}}{\sum_\tau \mathcal{R}^\tau_t l^\tau_t}$. Consequently, the bank equity constraint takes the expected inflation rate into account as well:

$$\mathbb{E}_t\Big[\frac{(1+r^D_t)d_{t+1}}{\pi_{t+1}}\Big] \leq \sum_\tau (1-\kappa^\tau_t)\mathbb{E}_t\Big[\mathcal{R}^\tau_{t+1}\Big]l^\tau_{t+1} \ . \tag{A.8}$$

Solving the representative bank's maximization problem, we obtain the following loan pricing schedule

$$q(\overline{m}^\tau_{t+1}) = \mathbb{E}_t\left[\left\{(1-\kappa^\tau_t)\underbrace{\left(\frac{\pi_{t+1}}{1+r^D_t} - \Lambda_{t,t+1}\big(1-F(\overline{\mu}_{t+1})\big)\right)}_{\text{Deposit Financing Wedge } \Xi_t} + \underbrace{\Lambda_{t,t+1}\Big(1-G(\overline{\mu}_{t+1})\Big)}_{\text{Bank-owner sdf } \overline{\Lambda}_{t,t+1}}\right\}\mathcal{R}^\tau_{t+1}\right] . \tag{A.9}$$

Different to the RBC version of the model, the deposit financing wedge takes into account that deposits are denominated in nominal terms. All else equal, a high inflation rate makes deposit financing even more attractive for banks.

Intermediate Good Firms. Since we specify the bank sdf in real terms, loan payoffs have to take the nominal loan denomination into account:

$$\mathbb{E}_t[\mathcal{R}^f_{t+1}] = \mathbb{E}_t\left[(1-\chi)q(\overline{m}^f_{t+2}) + \frac{\chi}{\pi_{t+1}}\left(1 - F(\overline{m}^f_{t+1}) + \frac{G(\overline{m}^f_{t+1})}{\overline{m}^f_{t+1}} - F(\overline{m}^f_{t+1})\varphi\right)\right] . \tag{A.10}$$

Their maximization problem now reads

$$\max_{k^f_{t+1}, l^f_{t+1}, \overline{m}^f_{t+1}} -\psi^f_t k^f_{t+1} + q^f_t\left(l^f_{t+1} - (1-\chi)\frac{l^f_t}{\pi_t}\right) + \mathbb{E}_t\Bigg[\widetilde{\Lambda}_{t+1}\cdot\Bigg\{\int_{\overline{m}^f_{t+1}}^\infty (p^f_{t+1}-\xi_{t+1})\cdot m_{t+1}\cdot k^\tau_{t+1} -$$
$$-\chi\cdot\frac{l^f_{t+1}}{\pi_{t+1}}dF(m_{t+1}) + \psi^f_{t+1}(1-\delta_K)k^f_{t+1} + q(\overline{m}^f_{t+2})\Big(l^f_{t+2} - (1-\chi)\frac{l^f_{t+1}}{\pi_{t+1}}\Big)\Bigg\}\Bigg] ,$$

subject to the default threshold $\overline{m}^f_{t+1} \equiv \frac{\chi l^f_{t+1}}{\pi_{t+1}(p^f_{t+1}-\xi_{t+1})k^f_{t+1}}$ and subject to the financing conditions given by banks' loan pricing condition (A.9).

Households and Monetary Policy. Since deposits are denominated in nominal terms, Equation (2) changes to

$$1 = \mathbb{E}_t\left[\Lambda_{t,t+1}\frac{1+r^D_t}{\pi_{t+1}}\right] + \omega_D\frac{d^{-\gamma_D}_{t+1}}{c^{-\gamma_C}_t} \ . \tag{A.11}$$

Together this implies that the effect of inflation on bank risk-taking is negligible in this model. To close the model, we assume that the central bank sets the nominal interest rate according to a Taylor-type rule:

$$1 + r_t = (1 + r^{SS})\pi_t^{\varphi_\pi} \ , \tag{A.12}$$

where the risk-free rate r_t is linked to the household sdf as follows:

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1} \frac{1 + r_t}{\pi_{t+1}} \right] \ .$$

We specify the policy rate in terms of an interest rate that is not traded in a market in our model. Thereby, we exclude interactions between the policy rate (and, thus, nominal rigidities) with deposit demand. In steady state, the real rate is simply pinned down by the household's time preference parameter β. Lastly, the resource constraint now features Rotemberg costs:

$$y_t = c_t + \sum_\tau i_t^\tau \left(1 + \frac{\Psi_I}{2} (\frac{i_t^\tau}{i_{t-1}^\tau} - 1)^2\right) + \frac{\Psi_P}{2} (\pi_t - 1)^2 + \frac{\theta_1}{\theta_2 + 1} \left(\frac{\tau_t}{\theta_1}\right)^{\frac{\theta_2+1}{\theta_2}} z_t^f + \varphi F(\overline{m}_t) + \zeta F(\overline{\mu}_t) d_t \ . \tag{A.13}$$

B Additional Numerical Results

In this section, we provide additional numerical results from our baseline model.

B.1 Carbon Tax Shocks

First, we show that the short run impact effects of the clean transition (Figure 1 and Figure 2) are similar to the effects of carbon tax shocks. Such a shock can be interpreted as a sudden shift in the political ability to implement taxes, which could simply be the election of an environmental-friendly party. Alternatively, one could think of events that make climate change and its costs more salient and, thus, motivate incumbent policymakers to suddenly tighten climate policy. For the remainder of the section, we fix the level of the carbon tax at a long run level of $p_t^{\text{carbon}} = 10\$/\text{ToC}$ and consider shocks to carbon taxes. Specifically, carbon taxes follow an AR(1)-process,

$$\tau_t = (1 - \rho_\tau)\tau^{SS} + \rho_\tau \tau_{t-1} + \sigma_\tau \epsilon_t^\tau \ . \tag{A.14}$$

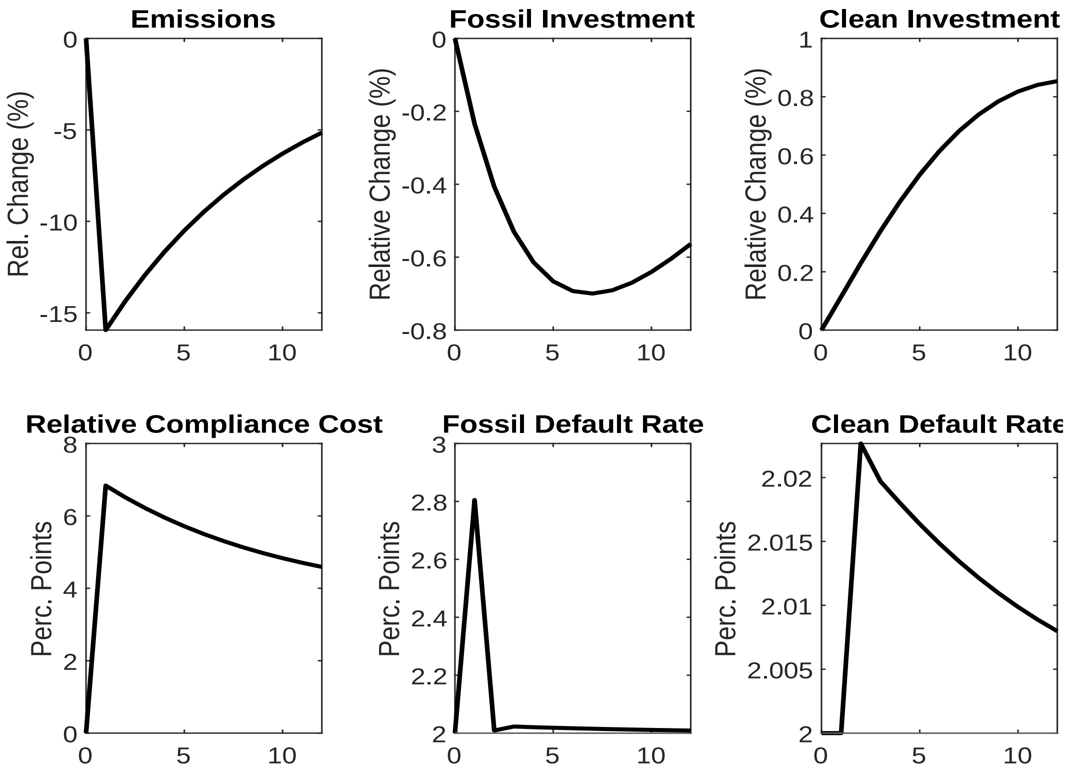
Its persistence is set to $\rho_\tau = 0.9$ and the shock variance σ_τ^2 implies that a one standard deviation shock corresponds to an increase of another 10$/ToC on impact. Figure B.1 displays the sectoral effects. Since abatement is costly, relative compliance cost ξ_t/p_t^f almost double from 4% to 7% and emissions decline by slightly more than 10%. Since the tax increase is transitory, emissions revert back to their steady state level.

The increase in compliance cost resembles a negative productivity shock to fossil firms. Their investment (upper middle panel) decreases on impact and reaches it trough after about 2 years. Likewise, clean investment increases by around 1%, with the peak being reached only after 3 years. Since fossil energy firms experience a sudden drop in their revenues, their default rate increases on impact from 2% to 2.8%, which is quantitatively relevant. It reverts to the steady state level relatively quickly.

Again, the opposite effect can be observed for clean firms, see the lower panel of Figure B.1. After the impact of the shock, clean firms engage in risk-taking. Their leverage remains above the pre-shock level for multiple periods. At the same time, fossil firms persistently de-leverage (bottom panel). This effect is consistent with results reported in Kacperczyk and Peydro (2022). The heterogeneous response of firm risk-taking is also reflected in the greenium (left middle panel of Figure B.1), which is negative on impact and turns slightly positive after a few quarters.

The macroeconomic implications are shown in Figure B.2. Since both energy goods are imperfectly substitutable, clean energy firms can not fully compensate the productivity loss of fossil energy firms: aggregate energy supply and, thus,

Figure B.1: Sectoral Effects of Carbon Tax Shocks

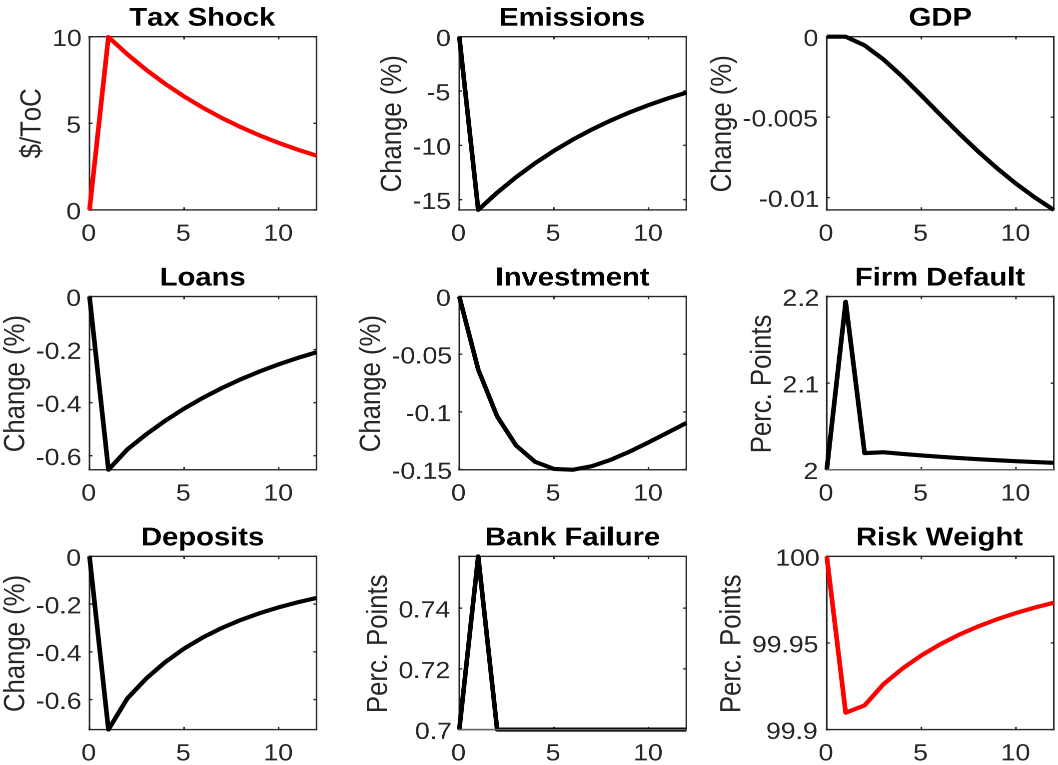


Notes: Impulse response to a 10\$/ToC tax shock, starting from a long run tax of 10\$/ToC.

economic activity as measured by GDP, real investment, and loan demand contracts. Furthermore the large increase in fossil energy defaults exceeds the decrease of clean defaults, such that aggregate defaults and bank failure go up. Notably, the effect on bank failure is very short lived: on impact, the realized aggregate loan payoff declines, such that the failure rate increases by around 0.06 percentage points.

However, since bank regulation is binding immediately, banks reduce their deposit supply immediately, such that the failure rate reverts to its steady state level in the quarter after the shock. The bottom left panel of Figure B.2 shows how bank capital regulation optimally responds to tax shocks. Consistent with the response of bank regulation to the perfect foresight transition, aggregate capital requirements decline temporarily.

Figure B.2: Macro Effects of Carbon Tax Shocks



Notes: Impulse response to a 10\$/ToC tax shock.

B.2 Transition

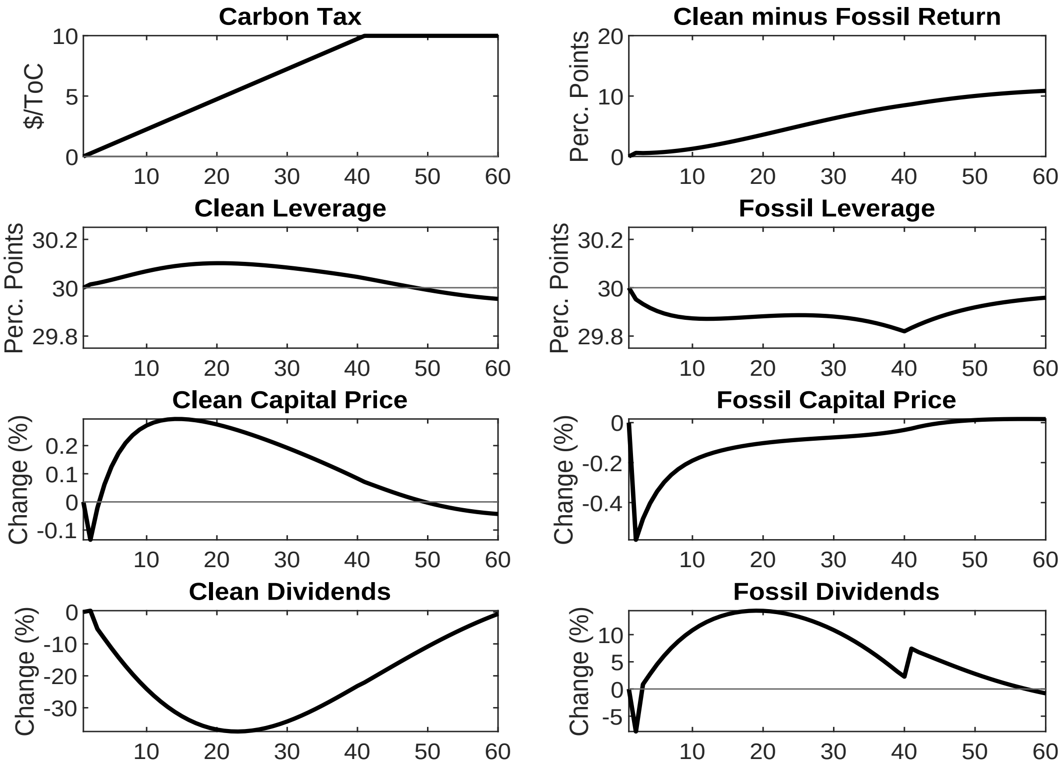
In this section, we show additional quantitative properties of our baseline model along the transition path, which is again given by a linear increase from 0 to 10\$/ToC over 40 quarters. The upper right panel of Figure B.3 shows the return index of a portfolio that is long in clean stocks and short in fossil stocks. The price of a sector-specific stock index ϕ_t^τ is defined through the following recursion

$$\phi_t^\tau = div_t^\tau + \mathbb{E}_t\left[\Lambda_{t,t+1}\phi_{t+1}^\tau\right] \tag{A.15}$$

Absent short-selling frictions, this portfolio can be set up at zero cost and provides a substantially positive return during the transition. Once the new steady state is reached after around 60 quarters, the return index flattens out.

The second row of Figure B.3 compares the leverage ratio at book values (l/k) for the clean and fossil energy sector, which is consistent with the sector-specific default risk shown in Figure 1. In the third row, we illustrate that during the transition the price for capital in the clean energy sector increases, while it declines

Figure B.3: Transition Path, Additional Variables



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value.

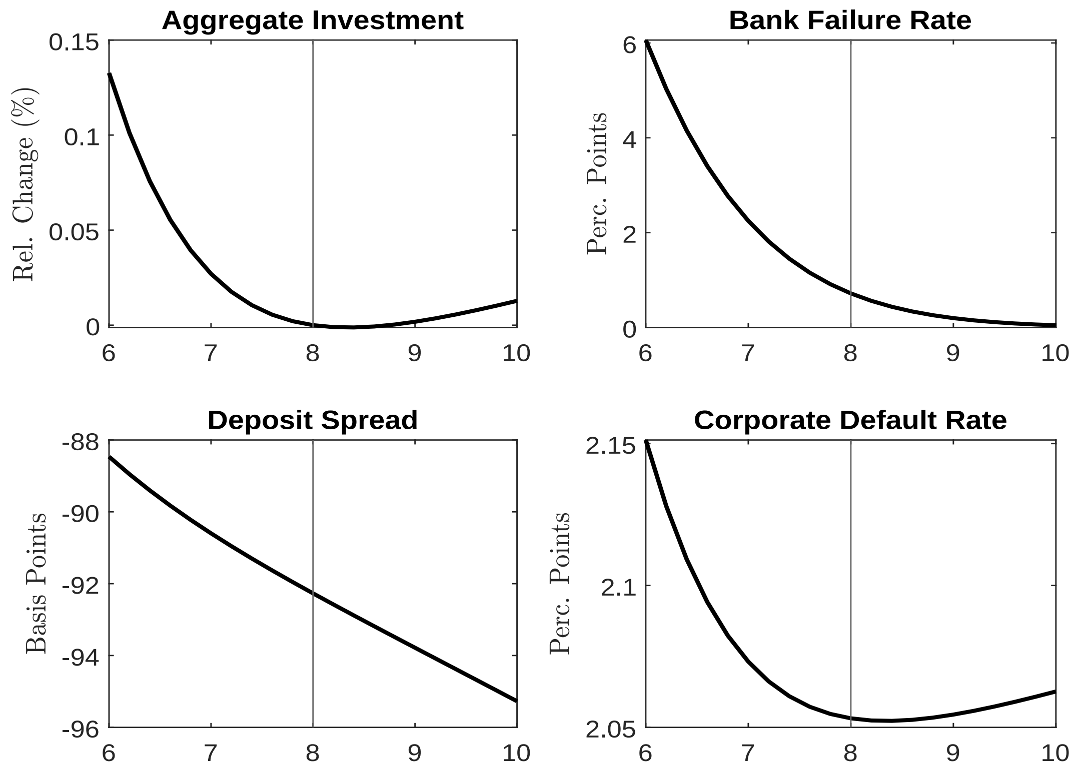
for the fossil sector, reflecting a temporarily high (low) demand for clean (fossil) capital goods. The time series of dividend payouts mirrors the investment pattern in each sector. During the transition, clean energy firms payout fewer dividends and instead increase their capital stock. Towards the new steady state, their dividend payouts converge to a permanently higher level than in the initial steady state. The opposite can be observed for fossil energy firms.

B.3 Long Run

This section presents the long run effects of bank regulation and carbon taxes of the baseline RBC model with perfectly diversified banks. The results are consistent with the permanent effects of the clean transition shown in Figure 1 and Figure 2.

Long Run Effects of Symmetric Capital Requirements In the symmetric case without carbon taxes, capital requirements directly affect bank failure rates and liquidity provision to households. Figure B.4 shows how a change in the symmetric capital requirement κ^{sym} affects macroeconomic aggregates. The top right panel demonstrates that tighter requirements reduce the failure probability of banks. At the same time, the deposit spread becomes more negative for higher capital requirements since deposits become scarcer and, thus, more valuable to households (bottom left panel). This represents the key trade-off for bank capital regulation in the long run.

Figure B.4: Macroeconomic Effects of Symmetric Capital Requirements



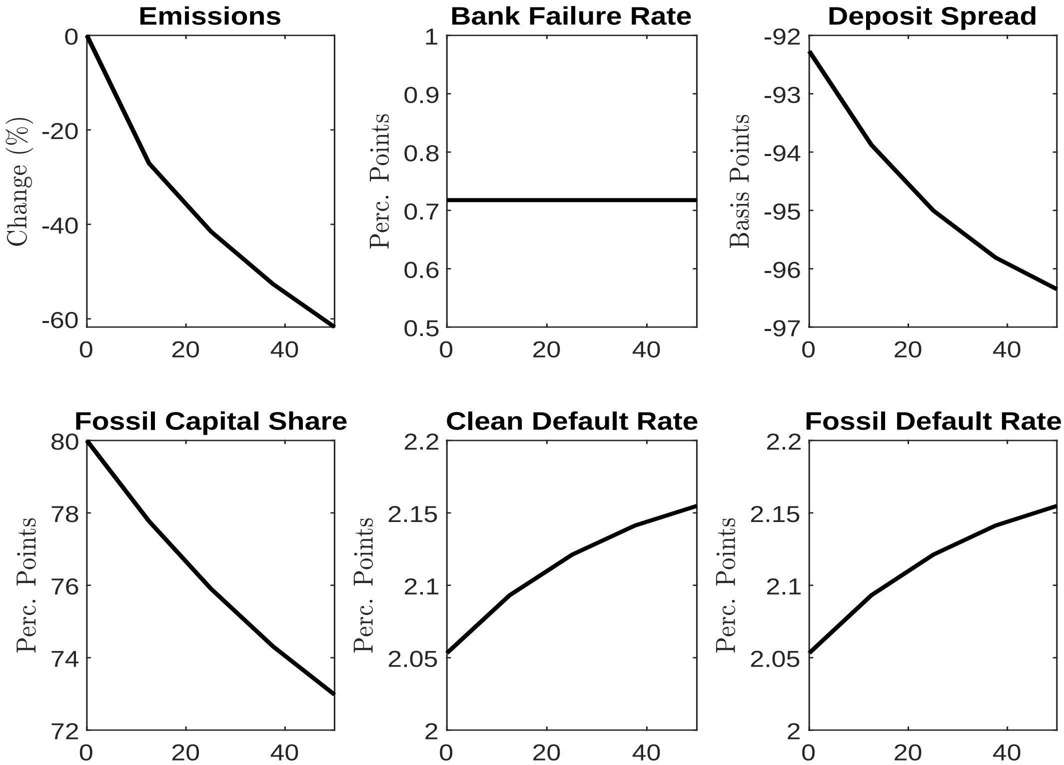
Notes: Welfare changes are expressed in consumption equivalents and are, like default costs, expressed relative to the baseline calibration. Bank failure probability and deposit spread are annualized.

Since risk-taking in the non-financial sector is endogenous in our model, it also affects optimal bank capital regulation. In the bottom right panel, we show how changes to the capital requirement affect firm risk-taking. If capital requirements are low initially, deposit supply is comparatively large and the deposit spread is moderately elastic. This follows from the curvature in household's valuation of deposits. Since a tightening decreases the share of loans financed by issuing deposits, loan supply contracts and firm's optimal capital structure is tilted towards equity. The corporate default rate falls. For high initial capital requirements, further increasing κ^{sym} still forces banks to reduce deposit supply, such that they become increasingly valuable. This increases the deposit financing wedge Ξ_{t+1} in banks' loan pricing condition (11), which makes increases the total benefit of deposit financing. Firms tilt their capital structure towards loans and the default rate rises.

Long Run Effects of Carbon Taxes The macroeconomic effects of a permanent carbon tax and its implications for bank capital regulation are summarized in Figure B.5. The top row shows that the decline of emissions due to carbon taxes is strongest for small taxes. This follows from the convex specification of adaptation costs $\frac{\theta_1}{\theta_2+1}\eta_t^{\theta_2+1}z_t^f$. Similarly, the damage/GDP ratio and fossil capital share decline more slowly as carbon prices increase.

Since the bank capital requirement is always binding, the long run bank failure rate does not depend on the carbon tax (middle row of Figure B.5). However, the reduction of bank balance sheets in response to a permanently lower aggregate loan demand implies a smaller supply of deposits to households and the deposit spread widens by around 8bp, which reduces bank funding costs and, ceteris paribus, increases loan supply. This increases corporate default rates for all firms by almost 0.1 percentage points, which is non-negligible from a macroeconomic perspective given the baseline level of 2.7%. We quantitatively re-evaluate the optimal capital requirement under the assumption that stringent carbon taxes are in place and find that a symmetric relaxation is optimal from a utilitarian welfare perspective, and also consistent with the optimal path of capital requirements along the clean transition.

Figure B.5: Long Run Effects of Carbon Taxes

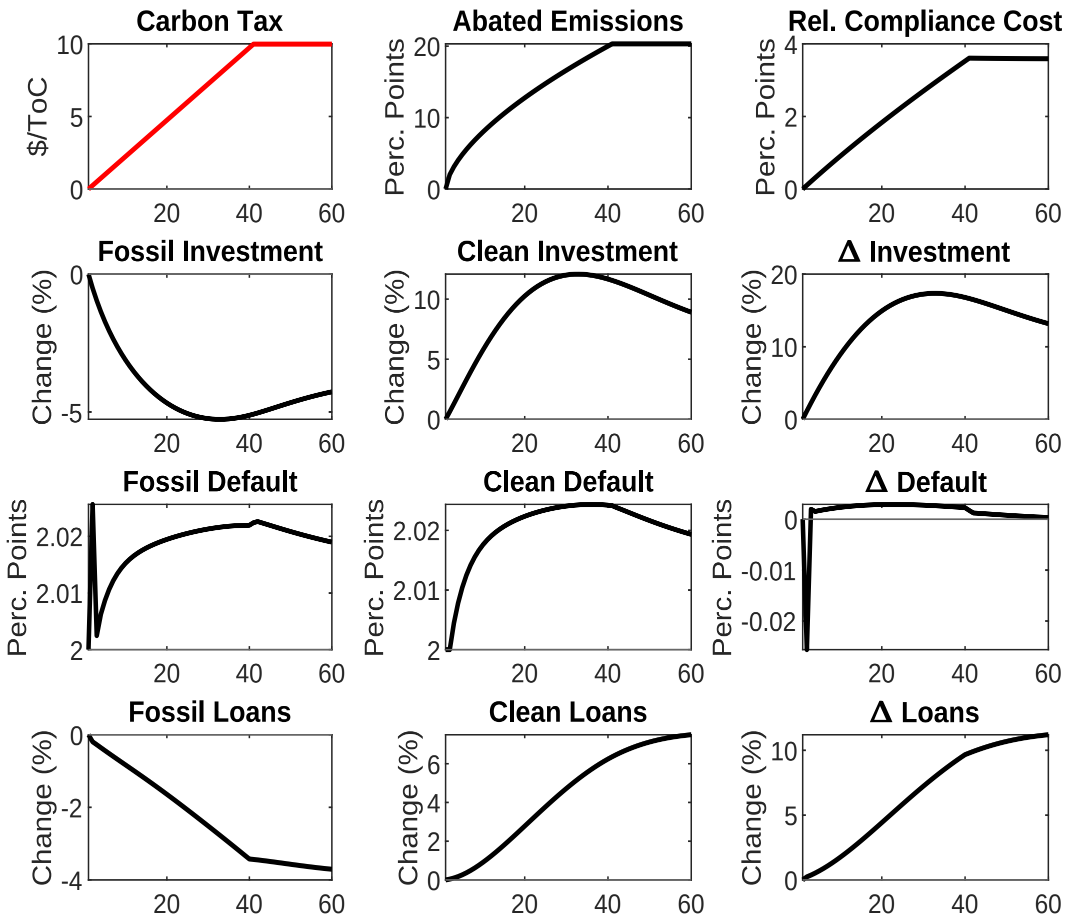


Notes: The carbon tax on the x-axis is expressed in \$/ToC.

C Robustness

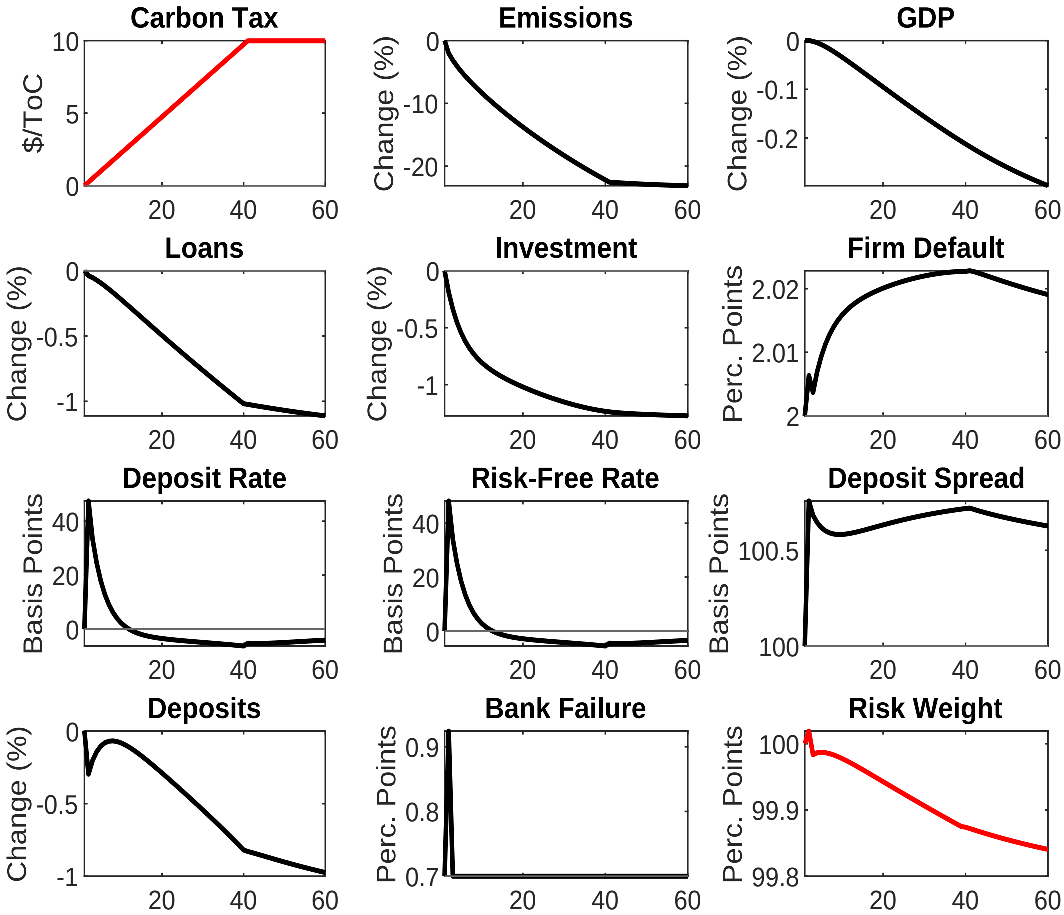
Low Deposit Demand Elasticity. The demand elasticity for deposits γ_D is a potentially important parameter for our analysis. In this section, we reduce the elasticity parameter to $\gamma_D = 0.6$. We re-calibrate the weighting parameter to $\omega_D = 0.012$ in order to keep the average deposit spread at 100bps. Not surprisingly, Figure C.1 shows that the sectoral implications of carbon taxes are largely independent of households' valuation of holding liquid deposits. Consequently, there is a similarly large decline in loan demand, bank balance sheets, and deposit supply. Compared to the baseline calibration, this translates into a slightly smaller widening of the deposit spread. However, the quantitative implications for optimal bank capital requirements are almost identical to the baseline.

Figure C.1: Transition Path, Fossil and Clean Sectors, Low γ_D



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10\$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. The right plot in each row shows the difference between clean and fossil sector variables.

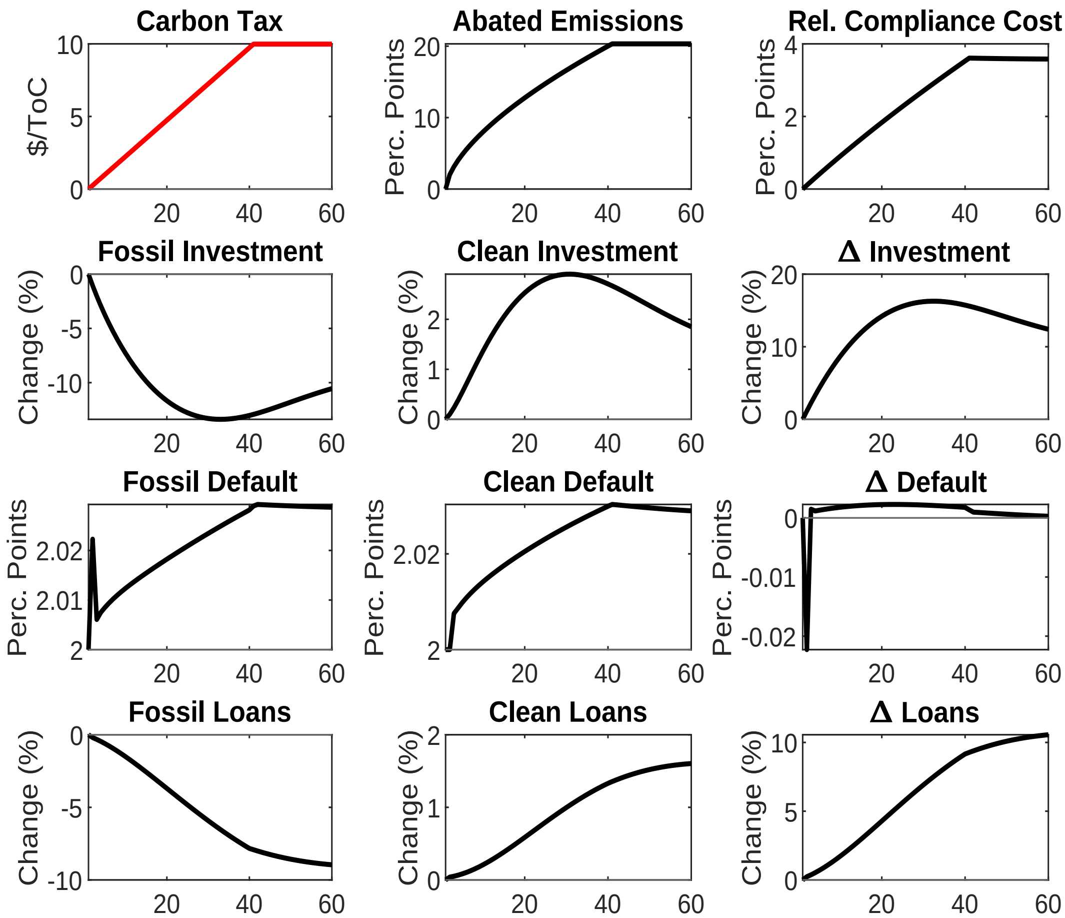
Figure C.2: Transition Path, Macro Side, Low γ_D



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. Capital requirements are expressed as "risk-weights" relative to the long run optimal capital requirement of 8%.

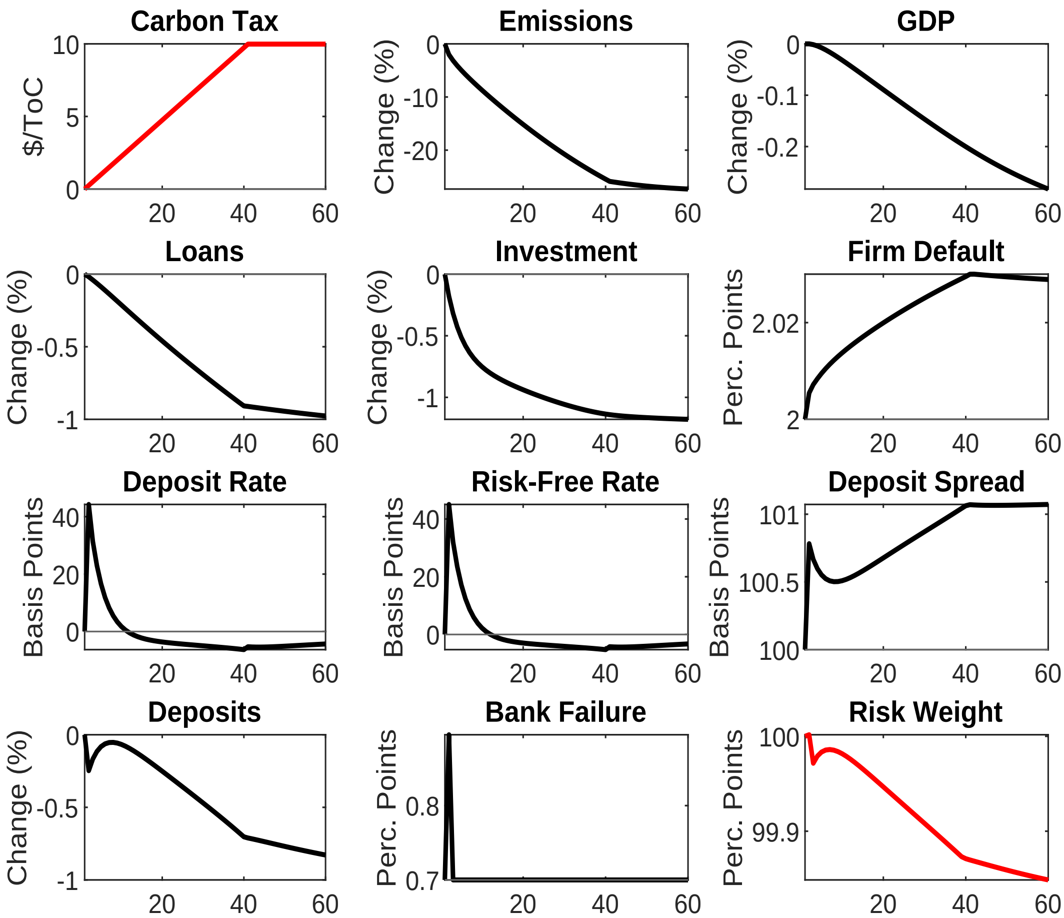
High Energy/Non-Energy Elasticity. We also show that our results do not materially depend on the very low elasticity between energy and non-energy intermediate goods, which was set to $\widetilde{\epsilon} = 0.2$ in the baseline model. We increase $\widetilde{\epsilon} = 3$ and adjust the energy weight to $\widetilde{\nu} = 0.535$ to ensure that the energy share in total GDP remains at 10%. Under this parameterization, there is a much stronger substitution away from energy in response to the transition: fossil investment declines much stronger than in the baseline calibration, as the second row of Figure C.3 shows. At the same time, clean investment is much less responsive. Notably, these substantial differences in the sectoral effects have only a minor effect on macroeconomic outcomes. On an aggregate level, loan demand and bank deposits contract slightly less in response to carbon taxes, such that the relaxation in capital requirements is slightly smaller than in the baseline.

Figure C.3: Transition Path, Fossil and Clean Sectors, High $\widetilde{\nu}$



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10\$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. The right plot in each row shows the difference between clean and fossil sector variables.

Figure C.4: Transition Path, Macro Side, High $\widetilde{\nu}$



Notes: Perfect foresight transition: linear carbon tax increase from zero to 10$/ToC over 40 quarters. All endogenous variables are computed while keeping capital requirements at their symmetric baseline value. Capital requirements are expressed as "risk-weights" relative to the long run optimal capital requirement of 8%.